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STO TECHNICAL REPORT **TR-HFM-252**

Aircrew Neck Pain Prevention and Management

(Prévention et gestion de la douleur cervicale des équipages d'aéronef)

Task Research Group Human Factors and Medicine (HFM) 252 Final Report.

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Task Research Group Human Factors and Medicine (HFM) 252 Final Report

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- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

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Table of Contents

List of Figures

List of Tables

List of Acronyms

ACDF	Anterior Cervical Discectomy and Fusion
ACM	Air Combat Manoeuvre
ACP	Aircrew Conditioning Programme
ACROM	Active Cervical Range of Motion
AFB	Air Force Base
AFHSIO	Air Force Human Systems Integration Office
AGARD	Advisory Group for Aerospace Research and Development
AGSM	Anti-G Straining Manoeuvre
ALSE	Aviation Life Support Equipment
AMS	AeroMedical Summary
ANVIS	Aviators' Night Vision Imaging System
ASL	Above Sea Level
ASP	Aviation Specialist Physiotherapist
AUS	Australia
BAF	Belgium Air Force
BFM	Basic Flight Manoeuvre
BMD	Bone Mineral Density
BMI	Body Mass Index
BPS	Bodily Pain Scale
CA	Canadian
CAN	Canada
CDU	Control Display Unit
CFEME	Canadian Forces Environmental Medicine Establishment
CoM	Centre of Mass
CROM	Cervical Range of Motion
CRS	Cervical Radicular Syndrome
CT	Computerised Tomography
CW	Counter Weight
DCF	Deep Cervical Flexor
DHM	Digital Human Modelling
DMED	Defence Medical Epidemiological Database
DRAM	Distress Risk Assessment Method
DRDC	Defence Research and Development Canada
DSSQ	Dundee Stress State Questionnaire
EFA	Eurofighter Aircraft
EMG	Electromyography
ET	Exploratory Team
FAS	Fatigue Assessment Scale
FE	Flight Engineer
FI	Fatigue Index
FIN	Finland
FINAF	Finnish Air Force
FINAFCOM	Finnish Air Force Communication
FJ	Fast Jet

FMS	Functional Movement Screening
FP	Flying Pilot
FS	Flight Surgeon
GER	Germany
G-LOC	G-induced Loss of Consciousness
GRC	Global Rating of Change
GSR	Galvanic Skin Response
HACS	Hybrid Air Cushioning System
HDD	Head Down Display
HFM	Human Factors and Medicine
HMD	Helmet Mounted Display
HMS	Head Mounted System
HPE	Human Performance Enhancement Program
HRV	Heart Rate Variability
HSI	Human Systems Integration
HSM	Head Supported Mass
HUD	Head Up Display
IAM	Institute of Aviation Medicine
IASP	International Association for the Study of Pain
ICC	Intra-class Correlation Coefficient
IHS	Inflatable Headband System
IMPM	Integrated MFTA/PDA Model
ISEK	International Society of Electromyography and Kinesiology
ISO	International Standardisation Organisation
ITA	Italy
JHMCS	Joint Helmet Mounted Cuing System
M&S	Modelling and Simulation
MCU	Multi Cervical Unit
MEL	Medical Employment Limitation
MET	Muscular Endurance Test
MFD	Multi-Function Display
MFTA	Mission, Function, Task Analysis
MOD	Ministry Of Defence
MoI	Moment Of Inertia
MR	Magnetorheological
MRI	Magnetic Resonance Imagery
MSI	Musculoskeletal Injury
MVC	Maximal Voluntary Contraction
NATO	North Atlantic Treaty Organisation
NAVAIR	US Naval Air System Command
NDI	Neck Disability Index
NFP	Non Flying Pilot
NHEXS	Neck Health EXercise Strategies
NLD	Netherlands
NOR	Norway
NPRS	Numeric Pain Rating Scale
NRC	National Research Council Canada

NSAID	Non-Steroidal Anti-Inflammatory Drugs
NVG	Night Vision Goggles
OMPQ	Orebro Musculoskeletal Pain Questionnaire
ORTWQ	Obstacle to Return To Work Questionnaire
OTC	Over The Counter
OTW	Out the Window
PCIMP	Physical Conditioning and Injury Mitigation Programme
PCRF	Primary Care Rehabilitation Facility
PDA	Physical Demands Analysis
PFT	Physical Fitness Test
PMHS	Post Mortem Human Specimens
POR	Portugal
PT	Physiotherapist(s)
PTI	Physical Training Instructor
QCT	Quantitative Computed Tomography
RAAF	Royal Australian Air Force
RADALT	Radar Altimeter
RAF	Royal Air Force
RAST	Running-based Anaerobic Sprint Test
RCAF	Royal Canadian Air Force
RCT	Randomised Clinical Trial
RNLAF	Royal Netherlands Air Force
ROM	Range of Motion
RTG	Research Task Group
RTP	Return to Play
RW	Rotary Wing
SAE	Society of Automotive Engineers
SCM	Sternocleidomastoid
SD	Standard Deviation
sEMG	Surface Electromyography
SENIAM	Surface Electromyography for Non-Invasive Assessment of Muscles
SF-36 BPS	Short Form-36 Bodily Pain Scale
SIMM	Software for Interactive Musculoskeletal Modelling
SME	Subject Matter Expert
SNS	Sympathetic Nervous System
SVED	Sagittal Vertical Extrusion Device
TENS	Transcutaneous Electrical Nerve Stimulation
THM	Tactical Helicopter Mission
TLF	Thoracolumbar Fascia
TLX	Task Load Index
TMD	Temporomandibular Disorders
TMJ	Temporomandibular Joint
ToR	Terms of Reference
TRX	Total-body Resistance Exercise
TSK	Tampa Scale for Kinesiophobia
UK	United Kingdom
US	United States

USAARL	United States Army Aeromedical Research Laboratory
USAF	United States Air Force
USN	United States Navy
V&V	Validation and Verification
VAS	Visual Analogue Scale
VIP	Very Important Person / passenger
WAnT	Wingate Anaerobic Test

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Finding solutions to aircrew neck pain would not have been possible without previous efforts from Working Group 17, a 1990 Technology Watch, and HFM-083 that reported on, researched, and studied the physiological effects of long term repeated exposure to sustained high-G. HFM-252 acknowledges the many work days that Dr. Barry S. Shender, Dr. Heather Wright Beatty, and Sarah E. Day spent in performing detailed edits, formatting citations and references, and generating an acronyms list, respectively, in the preparation of this report. The members would like to acknowledge the following contributors to this report: WGCDR Carlos Almenara (Royal Australian Air Force), Lori Brattin Basham (NAWCAD), Dr. Giovanni Fusina (DRDC), Dr. Justin G. Hollands (DRDC), Dr. Thomas Karakolis (DRDC), Dr. Patrick Mullie (University of Brussels), Umberto Placentino (Air Force Sport Center Italy), Mr Yuval Steinman (Center for Man in Aviation, RNLAF); and Dr. Viresh Wickramasinghe (NRC). We would also like to thank the HFM-252 Peer Reviewers: Lt Col Dr Damien Van Tiggelen (Military Hospital Queen Astrid); Lt Col Bert Thurman (ACOS Ops & Trg); Lt Col Med Jan Mertens (COMOPSMED); Maj Linda Bossi, Ret. (DRDC); William D. Fraser (Silatyuk Research); Col Frank Weber (Department of Research and Development, Bundeswehr); Dr. Vivienne M. Lee (Qinetiq); and Dr. Philip Whitley (Criterion Analysis, Inc.).

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NATO OTAN

S&T organization

Aircrew Neck Pain Prevention and Management

(STO-TR-HFM-252)

Executive Summary

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

A significant proportion of fixed- and rotary-wing aircrew in NATO air forces experience flight-related neck pain that is exacerbated by additional head-mounted equipment and non-ergonomic aircraft crew spaces. Thus, aircrew neck pain solutions must be found. Research Task Group (RTG) Human Factors and Medicine (HFM) Panel 252 on Aircrew Neck Pain had a mandate to study this problem and evaluate proposed mitigating solutions. The objective of this NATO RTG was to seek and recommend evidence-based administrative, procedural, ergonomic, engineering, preventative, and treatment solutions for the problem of aircrew neck pain.

RECOMMENDATIONS

Human Factors: NATO air forces should implement aircrew conditioning programmes that emphasise physiotherapy support, education, total lifestyle health promotion, individual guidance, cost and benefit assessments, and sufficient rest and recovery time to reduce the risk of developing or aggravating neck pain. Aviation medicine team members should provide personalized flying duty fitness recommendations, including gradual return to flying duties and appropriate, temporary, or permanent G-exposure limitations.

Body-Borne Equipment: The mass and inertia of future helmet systems (helmet, night vision goggles, and other peripherals) should not exceed those of current in-service systems, and remain balanced during critical aircrew tasks. Aircrew should have their helmets fitted properly and regularly to reduce neck pain, helmet slippage, hot spots, and pressure points. Procurement agencies must consider all helmet system requirements such as aircrew performance, impact protection, aircraft life support equipment integration, as well as aircrew neck pain.

Behaviours and Tasks: Aircrew should adopt biomechanically advantageous postures and aircraft should include ergonomic handles and supports whenever possible to reduce neck joint loading and muscle strain.

Aircraft Workspace: Recognising that aircraft modifications come with significant costs and airworthiness recertification requirements, certain aircraft displays and controls should be repositioned to promote biomechanically advantageous postures and reduce neck loading. For helicopters, track-and-balance maintenance and seat cushions can reduce vibration at head level.

Organisation: Neck pain should not be ignored. It is a problem shared by aircrew, clinicians, and command, and may require a shift in organisational culture. There is no ‘quick fix’ for the aircrew neck pain problem. Solutions must work synergistically and be implemented as soon as possible to minimise the risk of developing or aggravating neck pain. A cost-benefit analysis is essential to justify long-term comprehensive solutions.

Future Studies: Future studies include refining the HFM-252 neck pain survey, validating electromyography standards, updating helmet system mass properties guidelines, maturing seat vibration mitigation solutions, developing business case templates, and developing evidence to support the effectiveness of aircrew neck pain solutions in NATO air forces.

Prévention et gestion de la douleur cervicale des équipages d'aéronef

(STO-TR-HFM-252)

Synthèse

Énoncé du problème et objectif de recherche : Une part importante des équipages d'aéronefs à voilure fixe et à voilure tournante des forces aériennes de l'OTAN souffrent d'une douleur cervicale liée au vol, exacerbée par l'équipement porté sur la tête et par les espaces non ergonomiques alloués à l'équipage. Il est donc impératif de trouver des solutions à la douleur cervicale de l'équipage des aéronefs. Le groupe de recherche (RTG) « Douleur cervicale de l'équipage des aéronefs » de la Commission sur les facteurs humains et la médecine (HFM) 252 avait mandat pour étudier ce problème et évaluer les solutions d'atténuation proposées. L'objectif de ce RTG de l'OTAN était de rechercher et recommander des solutions au problème de la douleur cervicale de l'équipage des aéronefs, solutions fondées sur l'expérience dans le domaine de l'administration, des procédures, de l'ergonomie, de l'ingénierie, de la prévention et du traitement.

Recommandations : Facteurs humains : les forces aériennes de l'OTAN devraient mettre en œuvre des programmes de préparation de l'équipage qui insistent sur le soutien physiothérapeutique, l'éducation, la promotion de la santé générale par le mode de vie, les conseils individuels, l'évaluation des coûts et des avantages et un temps de repos et de récupération suffisant pour réduire le risque de développer ou d'aggraver une douleur cervicale. Les membres de l'équipe de médecine aéronautique devraient fournir des recommandations personnalisées d'aptitude au service aérien, incluant un retour progressif aux missions en vol et des restrictions adéquates, temporaires ou permanentes, d'exposition à l'accélération due à la pesanteur.

Équipement portatif : le poids et l'inertie des futurs systèmes de casque (casque, lunettes de vision nocturne et autres périphériques) ne devraient pas dépasser celui des systèmes actuellement en service et rester équilibrés pendant les tâches critiques de l'équipage. L'équipage devrait ajuster son casque correctement et régulièrement pour réduire la douleur cervicale, le glissement du casque, les zones d'échauffement et les points de pression. Les agences d'approvisionnement doivent étudier tous les besoins des systèmes de casque, tels que la performance de l'équipage, la protection contre les chocs, l'intégration de l'équipement de survie de l'aéronef, ainsi que la douleur cervicale de l'équipage.

Comportements et tâches : l'équipage devrait adopter des postures avantageuses sur le plan biomécanique et les aéronefs devraient inclure des poignées et des supports ergonomiques chaque fois que possible pour réduire la charge sur les articulations et les efforts musculaires du cou.

Espace de travail dans l'aéronef : sachant que la modification des aéronefs s'accompagne de coûts importants et d'exigences de recertification de la navigabilité, il faudrait déplacer certains affichages et commandes d'aéronef pour promouvoir des postures biomécaniquement bénéfiques et réduire la charge sur le cou. Dans les hélicoptères, l'entretien du réglage et de l'équilibrage et les coussins des sièges peuvent réduire les vibrations au niveau de la tête.

Organisation : il convient de ne pas ignorer la douleur cervicale. Ce problème est partagé par l'équipage, les médecins et le commandement et pourrait demander un changement de culture organisationnelle.

Il n'existe pas de « solution rapide » au problème de douleur cervicale de l'équipage. Les solutions doivent entrer en synergie et être appliquées au plus tôt pour minimiser le risque de développer ou aggraver la douleur cervicale. Une analyse coût-avantage est essentielle pour justifier les solutions complètes à long terme.

Études futures : les futures études incluent l'affinage de l'enquête sur la douleur cervicale du HFM-252, la validation des normes d'électromyographie, la mise à jour des principes directeurs des propriétés massiques du système de casque, le mûrissement des solutions d'atténuation des vibrations des sièges, le développement de modèles d'analyse de rentabilisation et l'acquisition de preuves appuyant l'efficacité des solutions qui luttent contre la douleur cervicale de l'équipage dans les forces aériennes de l'OTAN.

Management
&
Prevention

Human Factors & Medicine Panel
NATO Research Task Group 252

Aircrew Neck Pain

Chapter 1 – INTRODUCTION

1.1 BACKGROUND: SETTING THE CONTEXT

Aviation medicine aims to maintain the health and safety of aircrew in order to optimise performance in challenging airborne environments. However, increased burden, through application of technological advances in helmet-mounted devices combined with increased operational tempo and poor aircraft ergonomics, may have unintended negative consequences on aircrew health and safety, in particular debilitating and career-ending neck pain.

Fast jet, large fixed-wing and rotary-wing aircraft produce challenging acceleration (G), altitude, disorientation, thermal, and vibration environments that the human body must endure; thus, procedures and Aviation Life Support Equipment (ALSE; i.e., helmets, restraints, life vests, etc.) have been developed to protect aircrew. Advances in aircraft systems (including Head-Up Displays (HUDs), Helmet-Mounted Displays (HMDs) with associated sensors and Night Vision Goggles (NVGs)) have given allied aircrew a decisive advantage in all weather, day, and night conditions. As technological solutions emerge that promise increased capability in dangerous environments (e.g., NVG), aircrew often have a role in reducing the margin of safety that the new technology may not have accounted for in order to enhance combat effectiveness.

This research's operational context is illustrated by rotary-wing and fast jet composite scenarios in Annex A. These scenarios suggest a number of factors that may impact aircrew neck pain such as aircrew anthropometry, helmet systems, behaviours and tasks, flying and non-flying workspaces, and the organisation to which aircrew belong. For example from an organisational perspective, the operational tempo has increased over the past several decades [1] with major international operations including Kosovo, 1st and 2nd Gulf War, Afghanistan, natural disasters such as Haiti, Philippines, New Orleans, Syria, and Northern Iraq, as well as domestic crises. Not only has the number of missions increased, but so have the intensity and the complexity of each mission. All the while, aircrew must wear helmets and an increasing array of helmet-mounted devices for effective protection and enhanced visual and audio perception for all-weather, day, and night operating environments. These missions have driven many aircrew and aircraft to their physical, cognitive, and technological limits, and solutions for aircrew neck pain must be found.

1.2 AIRCREW NECK PAIN FRAMEWORK

Neck pain survey results support the postulate that helmet-mounted system factors combined with higher operational tempo (mission intensity, duration, and frequency) increase the risk of aircrew neck pain [2], [3], [4], [5]. Although various independent research efforts have tried to solve the problem, no single solution has been found to this multifactorial problem.

The NATO Human Factors and Medicine Exploratory Team 126 (HFM-ET-126) on Aircrew Neck Pain was set up in 2013 and was intended to gather aircrew neck pain research from member nations that would ultimately produce solutions [6]. HFM-ET-126 quickly recognised that an integrated, coordinated multinational and interdisciplinary team approach was needed to address the aircrew neck pain problem and deliver recommendations to mitigate aircrew neck pain.

Thus, the Research Task Group (RTG) Human Factors and Medicine (HFM) Panel 252 on Aircrew Neck Pain has a clear mandate to contextualise and understand aircrew neck pain, conduct the necessary research that evaluates a variety of mitigating solutions, and generate recommendations for reducing the risk and prevalence of aircrew neck pain. Figure 1-1 is a graphical summary of key topic areas, possible causal factors, and possible solutions, which were proposed during the ET-126 meeting, and is explored in detail in this report.

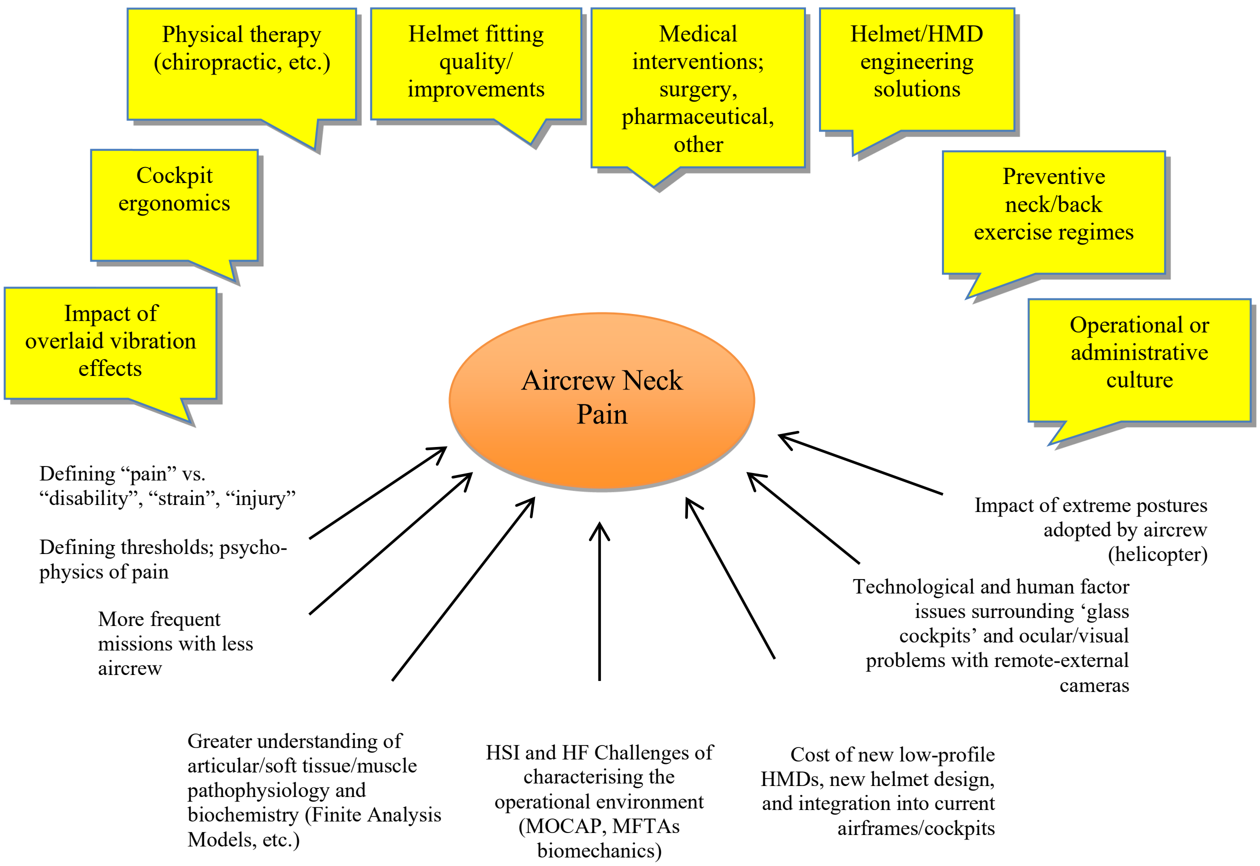

Figure 1-1: Factors that Affect Aircrew Neck Pain from ET-126 Meeting [6].

Aircrew neck pain is complex, yet a conceptual framework helps to organise and knit together possible causal factors and their corresponding solutions, in a logical and coherent fashion. The resultant framework has allowed the research task group to systematically develop an effective programme of work that addresses the Terms of Reference (ToR) objectives listed in Annex B.

Figure 1-1 details a number of factors and solutions. A conceptual model of the issues would help bring these factors together and give a clearer picture of how a package of solutions could be employed. One such framework organises the causes of musculoskeletal complaints into five key elements: Exposure, Dose, Response, Worker's Capacity, and Ergonomic Interventions [7]. Annex C describes this model in detail.

From Annex C, the main themes identified are re-organised into five possible factors of neck pain as follows: Human factors[1] (who aircrew are), Body-borne Equipment (what aircrew wear), Aircrew Behaviours (how

[1] Note well the lowercase *f* so as not to confuse this possible neck pain causal factor with the Human Factors discipline. Other terms were discussed, such as Aircrew Factors, Operator Factors, Human-Related Factors, and Human Characteristics – all with different advantages and disadvantages.

aircrew perform tasks), Aircraft Workspace (where aircrew work), and Organisation factors (when and why aircrew fly) as shown in Figure 1-2. Table 1-1 summarises the definition for each factor, and the factors are discussed in more detail below.

Figure 1-2: Aircrew Neck Pain Possible Causal Factors.

Table 1-1: NATO HFM-252 Aircrew Neck Pain Causal Factors.

Term	Definition
HUMAN FACTORS	Human factors refer to age, sex, anthropometry, strength, flexibility, range of motion, pain history, and other personal physical and psychosocial characteristics that might contribute to aircrew neck pain.
BODY-BORNE EQUIPMENT	Body-borne Equipment refers primarily to equipment worn by aircrew. This equipment has additional mass and inertia, which shifts the CoM and balance. It includes equipment such as NVGs, HMDs and counterweights.
AIRCREW BEHAVIOURS	Aircrew Behaviours refer to not only the tasks that aircrew do during the course of a mission, but also the positions, postures, and postural sequences that they use while performing each task. Physical demands information (i.e., joint angles, duration, frequency, and forces) can be associated with each postural sequence, from which one can calculate the force and moment loads on neck joints.
AIRCRAFT WORKSPACE	Aircrew member's workspace impacts neck pain. Cockpit/cabin instrument layout dictates, in large measure, the required postures to see displays and manipulate controls. These positions place aircrew in non-neutral positions thus contributing to higher neck loads (e.g., helo-hunch). The Aircraft type itself impacts neck pain. Fast jets produce high G, which amplifies any external neck loading, while helicopters produce vibration that adds a second order component to neck loads.

Term	Definition
ORGANISATION	Organisation Factors refer to the command and control elements within which aircrews operate. These factors extend from the individual squadron through the air force and military chains of command to even the political decisions that determine missions, aircraft type, mission length, and scheduling, recruitment and selection, education and training.

Human factors are meant to capture an individual's personal characteristics that may impact their neck pain. From the recent multi-nation survey [4], sex was a significant predictor for pain related to flying, with females reporting a much higher risk of pain. Extreme (short and tall) heights (anthropometry) were associated with a higher risk of pain after flying, along with persistence or length of worst symptoms. Increasing age was associated with a greater risk of length of worst symptoms and length of average symptoms, and a decreased risk of pain during moderate G with NVGs. There may be no obvious solution that addresses sex, age and anthropometry, except perhaps new guidelines for aircrew selection. On the other hand, neck-related characteristics like strength and flexibility would fall under Human factors and is discussed in Chapter 4 as part of the Professional Athlete Model and Aircrew Conditioning Programme.

Body-borne Equipment seems to be an obvious factor that emerges from the survey results. This factor refers to mass, Centre of Mass (CoM), and mass Moment of Inertia (MoI) properties of head-borne equipment. Intuitively, one can imagine that the more equipment on the head and helmet, the greater the risk of neck injury. Just as intuitively, a solution would be to remove as much mass off of the neck as possible by introducing lighter better-balanced helmets, NVGs, HUDs, and HMDs. Also, a Human Systems Integration (HSI) approach for implementing solutions should be employed so that a proposed solution does not compromise other parts of the system. For instance, simply removing material from a helmet to make it lighter may compromise the integrity of the helmet and therefore put at risk any impact protection or may require a different Helmet Fit procedure.

Aircrew Behaviours take into consideration the impact of body posture and movement on neck pain due to how tasks are performed by aircrew. This factor is often coupled with the Body-borne Equipment, and specifically the inertial properties of neck-borne devices. Injury may occur when performing tasks that require dynamic movements as a series of postures or postural sequences (e.g., checking 'six' whilst under G), or it may occur when aircrew hold a relatively static position or posture for extended periods of time (e.g., programming the centre console's Flight Management System for twenty minutes), or conducting multiple missions with inadequate rest in between. Thus, aircrew behaviours (tasks and postures) clearly impact aircrew neck pain. Possible solutions related to the Aircrew Behaviour factor may include re-learning certain tasks to assume a more neutral neck position by, for instance, rotating the trunk more than the neck to operate a centre console or checking 'six'.

While Human factors, Body-borne Equipment, and Aircrew Behaviour may be considered as proximal contributors of neck pain (clearly related to each other), Workspace and Organisation factors may be considered as distal contributors of neck pain.

Aircraft Workspace factors refer to the aircraft type, vibration and G, and ergonomic design of workspaces that impact neck pain. For fast jet aircrew, high G and unpreparedness when pulling G increase the risk of injury. For helicopter aircrew, poor ergonomics often produce 'helo-hunch', and vibration tends to aggravate neck pain after many night missions. Generally speaking, fast jets produce high-G, short-duration neck loads, while helicopters produce low-G, long-duration neck loads. Either case may lead to neck injury and promote neck pain. However, neck pain pathology and (therefore) solutions for fast jets may be different than for helicopters. That is, fast jet solutions may need to focus on limiting G exposure through technical or procedural means, while helicopter solutions may focus on passive or active seats that mitigate vibration transmission. Note that an administrative means to limit G could fall under Organisation Factors (e.g., 'for mission X, aircraft shall not exceed 4 G'). This is an example of a solution that may overlap multiple factors.

Organisation factors may contribute to neck pain, but are not necessarily found in the aircraft. Organisation factors include guidelines for aircrew selection, seniority, training requirements, Aircrew Life Support Equipment (ALSE) and Helmet Fit requirements, flight scheduling, and mission frequency, to name a few. Any solution that addresses organisation factors (such as optimal scheduling or "Smart Scheduling") will likely require some level of endorsement from the organisation.

It can be argued that the mission itself (as determined by the organisation) impacts neck pain. Any particular mission (e.g., search and rescue, surveillance, etc.) would infer a certain mission intensity, sortie duration, aircraft type, aircrew, equipment, and ultimately aircrew tasks and postures. For instance, some missions may require more aggressive aircraft manoeuvres, requiring aircrew to perform frequent anti-G straining manoeuvres. Aggressive aircraft manoeuvres may increase the risk of injury or aggravate existing neck pain.

In summary, these five possible causal factors provide a framework enabling a common taxonomy to understand and discuss the problem and then propose, develop, test, and recommend various solutions. Figure 1-3 illustrates how the framework could be used to categorise various factors and solutions. Note that this proposed framework is a simple listing of five prominent factors and does not refer to the assumed relationships between them. In fact, these relationships do exist and these factors overlap each other. However, the intent of the framework is to have a categorisation scheme around which we can develop solution recommendations that address these possible causal factors.

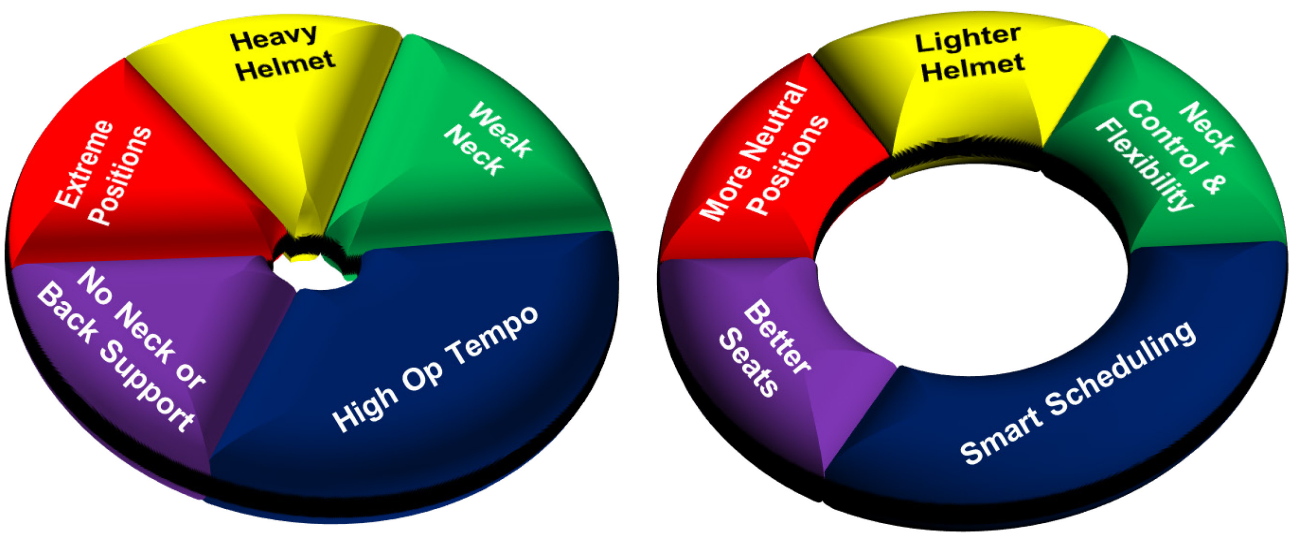

Figure 1-3: Examples of (Left) a Specific Factor Within Each Category that Impacts Neck Pain and (Right) a Solution Within Each Category that Reduces the Risk of Neck Issues.

1.3 OBJECTIVES

The overall objective of this NATO RTG is to seek and ultimately recommend creative administrative, procedural, ergonomic, engineering, preventative, and treatment solutions to aircrew neck pain. The nature of the problem demands a multidisciplinary team including biomechanists, human systems integration specialists, ergonomists, physiologists, medical specialists, physiotherapists, and operators. See Annex B for the specific RTG objectives as outlined in the ToR.

This work builds upon previous NATO working groups in this area of research. The first NATO effort was Working Group 17, established by the Aerospace Medical Panel of the former Advisory Group for Aerospace Research and Development (AGARD) that resulted in an advisory report on the musculoskeletal and vestibular effects of long-term repeated exposure to sustained high G [8]. That Working Group was followed by a Technology Watch that reviewed research data and published articles in the 1990s related to cervical spinal injury from repeated exposures to sustained acceleration [9]. This was followed by HFM-083 that studied the effects of sustained high G on the cervical spine [10].

1.4 REPORT CHAPTERS

The introduction sets the context for the RTG and the research to be conducted, and clearly outlines the research objectives. Chapter 2 presents aircrew neck pain epidemiology and the operational impact as well as a working definition for pain. Chapter 3 explores various metrics and methods for investigating aircrew neck pain. These chapters set the foundation for proposing and evaluating aircrew neck pain solutions.

The remainder of the report is organised with respect to the five categories of possible causal factors. Since these factors overlap, the chapters also overlap, to some extent, as well. Each chapter presents the issues and factors related to aircrew neck pain, followed by descriptions of the related mitigating solutions. Chapter 4 examines human-related or human factors and solutions. Chapter 5 investigates how Body-borne Equipment impact neck pain, and possible solutions for this causal factor. Chapter 6 focuses on Aircrew Behaviour, presents studies that captured and analysed aircrew tasks and postures, and proposes revised task postures and task distribution that mitigate neck pain. Chapter 7 includes Aircraft Workspace proposed solutions in terms of Ergonomics and Vibration and G mitigation. Chapter 8 presents some ideas that the Organisation should consider when integrating solutions into operations.

The report concludes by summarising the administrative, procedural, ergonomic, engineering, preventative, and treatment recommendations to reduce the risk of aircrew neck pain. It also provides suggestions on aircrew neck pain future work.

1.5 REFERENCES

[1] Castro, C.A., and Adler, A.B. (1999). OPTEMPO: Effects on soldier and unit readiness. Parameters, Autumn 1999, 86-95.

[2] Chafé, G.S., and Farrell, P.S.E. (2016). Royal Canadian Air Force CH-146 Griffon aircrew 2014 spinal musculoskeletal trouble survey. Toronto, Canada: Scientific Report, DRDC-RDDC-2016-R179, Defence Research and Development Canada, Toronto, Canada.

[3] Dehez, É. (2014). Rachialgies chez le personnel navigant sur hélicoptère : Enquête multicentrique par questionnaire anonyme portant sur 312 navigants sur hélicoptère français. (Diplôme d'état de docteur en médicine), Université de Bordeaux, Bordeaux, France. (102).

[4] Fraser, W.D., Crowley, J.S., Shender, B.S., and Lee, V.M. (2015). Multinational survey of neck pain in rotor-wing aircrew, p. 24. TTCP Technical Report DOC-HUM-01-2015: The Technical Cooperation Program.

[5] Wickes, S.J., and Greeves, J.P. (2006). Occupation and lifestyle contributors to flight-related neck pain. Aviation Space and Environmental Medicine, 77(3), 199.

[6] NATO. (2013). North Atlantic Treaty Organization (NATO): Terms of Reference (ToR) HFM-ET-126 Approval for Transition to TG on Aircrew Neck Pain. Paris, France: Collaboration Support Office – NATO S&T Organization.

[7] van den Oord, M.H.A.H. (2012). Prevention of flight-related neck pain in military aircrew. (Doctor of Philosophy), University of Amsterdam, Amsterdam, the Netherlands. (ISBN 978-90-804423-0-6).

[8] AGARD. (1994). Advisory Group for Aerospace Research and Development (AGARD): The musculoskeletal and vestibular effects of long-term repeated exposure to sustained high-G. Neuilly-sur-Seine, France: NATO RTO.

[9] AGARD. (1999). Advisory Group for Aerospace Research and Development (AGARD): Cervical spinal injury from repeated exposures to sustained acceleration: RTO Technical Report 4. Neuilly-sur-Seine, France: AGARD Aerospace Medicine Panel.

[10] NATO. (2008). North Atlantic Treaty Organization (NATO): Review of National Work Programmes on the Long-Term Effects of Sustained High-G on the Cervical Spine: TRO-TR-HFM-083. Neuilly-sur-Seine, France: NATO.

Chapter 2 – AIRCREW NECK PAIN EPIDEMIOLOGY, DEFINITION, AND OPERATIONAL IMPACT

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2.1 EPIDEMIOLOGY

In this chapter we will be looking at the epidemiology of neck pain. Previous works have defined neck pain independently and the authors of this report believe that improvements can be made to our understanding if we use common definitions going forward. To that end, Section 2.3 draws together a definition of neck pain and further goes on to define flight-related neck pain. Finally, it will discuss some of the operational impacts of flight-related neck pain.

2.1.1 Neck Pain in the General Population

Neck pain is a long-standing and well-documented problem, not just for aviation, but for numerous other occupational groups and the general public worldwide. The impact of neck pain on society is underestimated, even though neck pain is the fourth leading cause of disability internationally [1].

Approximately half of the general (or civilian) population experiences clinically important neck pain each year [2]; the annual prevalence of neck pain varies from 27.1% in Norway to 47.8% in Québec, Canada [3]. In Canada, two-thirds of the population will experience significant neck pain during their lifetime [4].

Risk factors associated with neck pain include age, sex, previous musculoskeletal pain, occupation, high job demands, low occupational social support, job insecurity, poor job satisfaction, awkward work postures, low physical capacity, poor computer workstation design, headaches, emotional problems, smoking, and poor physical work environment. Most occupational neck pain results from complex relationships between individuals, the workplace, and risk factors. Unfortunately, no prevention strategies have been shown to reduce the incidence of neck pain in workers [5].

2.1.2 Neck Pain in Aviation

In their recent review, Harrison et al. [6] point out that neck pain and injury have long been known as risks for pilots of fixed-wing fighter aircraft that are capable of high +Gz forces, but especially since the 1990s, helicopter crews have begun to see rising rates of neck problems. Classically, helicopter flying was always associated with lumbar / low back problems, but several factors led to increasing concern about potential neck problems as well: more female aircrew, more night flying, and more technology being attached to the flight helmets, for example. However, as noted by Xiao and Farrell [7] in their historical review of the extensive Canadian neck- and back-trouble[1] research programme, cervical spine problems are not new, dating back to the early helicopter days, but were initially overshadowed by more frequently reported low back symptoms.

The aeromedical literature is replete with reports, reviewed in this section, documenting neck pain problems in various aircrew populations and aviation platforms. Most of these reports cannot be used to determine causation or excess risk, due to the lack of exposure information or any control group, but they do document aeromedical problems with potential effects on safety and operational effectiveness, and can help identify possible and plausible factors that may correlate with chronic neck pain. Multiple comorbidities make it difficult to determine etiologic factors [6]. Recently, there have been attempts to improve the rigor of the epidemiological research. Selected recent studies with broad application are briefly presented below:

1) Lawson et al. [9] used a survey methodology to elucidate the overall risk and demographic/occupational predictors of neck pain in professional aviators. There were 413 surveys characterising the severity and character of neck pain symptoms that were administered to a multinational cohort of pilots and a non-aviator control group. The overarching conclusion was that the pilot profession, most notably high-performance and long-haul cargo/passenger airframes, displays an increased risk of neck pain symptoms.
2) Rice and Rizo [10] conducted an epidemiological analysis of health databases in the United States (US) Department of Defense. The objective was to determine the incidence of service-related cervical disorders among aviation personnel to determine if there were significant differences among aviation platforms. Using the Department of Defense Armed Forces Health Surveillance Center's Defense Medical Surveillance System, [10] queried International Classification of Diseases -9 codes related to acute cervical injury on flying status from 2008 to 2013. Preliminary data revealed an incidence density of cervical disorders in rotary-wing platforms for all services of 5.34 per 1000 person-years compared to 3.22 per 1000 person-years for tactical fixed-wing platforms, and 3.40 per 1000 person-years in non-tactical fixed-wing platforms [10].

[1] Neck trouble is defined as an ache, pain, discomfort, or numbness [8], and is specific to Defence Research and Development Canada studies.

3) Shiri et al. [11] reviewed published neck pain and cervical disease studies of military pilots and aircrew. Twenty studies were selected for the meta-analysis. Overall, no differences were found in neck pain prevalence, cervical disc degeneration, low back pain, or lumbar disc degeneration among fighter pilots and helicopter or transport/cargo pilots. Moreover, the prevalence of cervical or lumbar disc degeneration did not differ between fighter pilots and non-flying personnel. The authors commented that previous studies frequently did not control for age and other potential confounders, accounting for frequently reported correlations. However, fighter pilots' exposure to the highest G forces did correlate with higher prevalence of neck pain. Correlations with flight hours were inconsistently supported.

In some cases, flying personnel have been found to have lower prevalence of neck pathology than the general population. Pippig [12] found a higher rate of "inter-vertebral-disc-induced lesions of the cervical and lumbar spine," as assessed by radiography, in air traffic controllers (13%) (control group) than in transport aircraft pilots (6.6%), jet pilots / weapon systems officers (6.6%), and helicopter crew (9.9%).

While these studies may appear to disagree, it is not surprising that studies with different methodologies arrive at qualitatively different conclusions. But the comparisons among various air platforms and populations, while interesting from a public health standpoint, do not lead to solutions for neck pain. It is more important, in seeking to improve safety and health, to search for preventive and treatment strategies, which may depend on pathophysiological details that are unique to particular air platforms or aircrew populations.

2.2 OPERATIONAL FACTORS

2.2.1 Neck Pain and Aircraft Type

Aircraft Type, as a determinant of neck pain aetiology and risk, implies a complex set of occupational exposure factors, including cockpit/cabin ergonomics, vibration, acceleration, as well as the varieties of life support equipment worn in various flight environments; even aircrew behaviours that may contribute to neck pain vary across platforms.

Neck injuries that occur in the high +Gz environment tend to be more acute, and are frequently linked to a specific injurious event, whereas the typical helicopter pilot's neck pain is gradual in onset and chronic, similar to a musculoskeletal overuse injury. As fixed-wing helmets have become more technology-laden, and helicopters more agile, these patterns blur. But since the different mechanisms of injury will lead to different countermeasure strategies, this literature review is first organized by platform – fixed-wing (fighter, then transport) and rotary-wing. Then, as the hazards of helmet-mounted technologies are similar across different aircraft platforms, head-supported mass challenges will be presented together. These more detailed reviews will be presented in the next section.

2.2.2 Neck Pain and Injury in High-Performance Fixed-Wing Aircraft

For many years, neck pain and injury have been well-known problems for pilots flying fixed-wing fighter aircraft. The first reported case appeared in the literature in 1959, and described a flexion injury to a student pilot after a +9 Gz emergency pull-out in an AT-4 aircraft [13]. While this case was notable because of the persistence of neurological symptoms, it likely was not the first G-related neck injury in aircrew.

Since this early report, high-Gz exposure, as encountered in highly manoeuvrable fighter aircraft, has been the most frequently reported and well-established cause of neck pain and injury in pilots. In reviewing the worldwide literature, it will be seen that, while the most obvious and notorious source of neck injury in these agile aircraft is G, there are many other factors at play. The multifactorial nature of the aircrew neck injury problem complicates the selection of countermeasures, as will be discussed later in this report. For reviews of the anatomy, physics, and the relevant early aeromedical literature, the reader is referred to previous NATO panel reports [14].

In the late 1980s, reports began appearing more frequently in the aeromedical literature, documenting a concern among military air forces worldwide about neck problems in fast jet aircrew. It was the case of a Norwegian flight surgeon who suffered a significant cervical injury while flying in the back seat of an F16-B aircraft, thus providing detailed objective data that prompted the considerable ensuing aeromedical interest [15]. From the United States, Knudson et al. [16] found that 74% of F/A-18 Navy pilots had experienced an acute flight-related neck injury, while Vanderbeek [17] reported that nearly half of surveyed United States Air Force (USAF) jet pilots had suffered flight-related neck injury just in the previous 3-month period, with 9% describing their injury as ‘significant.’

Reports of neck pain in fast jet pilots from European air forces also began to appear with increasing frequency. Finnish fighter pilots were reported to have a 37.9% cumulative incidence of acute in-flight neck pain, which correlated with accumulated flight hours [18].

Fighter pilots in the Royal Australian Air Force were surveyed in Ref. [19], who reported that 84% had experienced a neck injury under +Gz, most of which were described as simple muscle sprains. A 2016 review of 115 Royal Australian Air Force fast jet aircrew explored the prevalence of ‘operationally significant neck pain’ [20]. This report identified the year-prevalence of operationally significant neck pain to be 60%, with affected aircrew typically experiencing 2 – 4 discrete episodes of neck pain per year, each lasting 3 – 5 days. Flying-related neck pain was most strongly linked to adopting the ‘check six’ position under G (mean 8.8 points on a 10-point scale), followed by helmet-mounted equipment (Joint Helmet-Mounted Cuing System (JHMCS), mean 7.3 points on a 10-point scale; NVGs, mean 6.2 points of a 10-point scale). By contrast, high-G flying in a helmet without head-supported masses was only weakly linked to neck pain (mean 3.2 points on a 10-point scale). Most aircrew (93%) reported that their flying performance had been negatively impacted by neck pain. For many aircrew (23%) the neck pain was sufficiently severe that they had to stop flying. For those who continued to fly despite their neck pain, a significant proportion (35%) report that they consciously limit the extent of neck movement in the cockpit, especially during Basic Flight Manoeuvre (BFM) and Air Combat Manoeuvre (ACM); 30% report a preference to avoid wearing the JHMCS unless critical for mission success (or avoid flying sorties where JHMCS are required), and 10% avoid wearing NVGs (or flying NVG sorties) if possible; 21% limit high-G flying, either by flying a more benign sortie by limiting the magnitude, duration, or onset rate of G, or by avoiding high-G sorties if possible; 11% report operational work-arounds and compromises, including using the mirrors rather than move their heads as much, using their experience to anticipate or predict the location of an opponent rather than moving their heads to track them visually, and accept that some aspects of operational performance will be compromised. Of interest, only 35% of respondents indicated that they undertook neck-conditioning exercises twice a week or more; however, 35% reported that they did so less than once a month or not at all. Flying-related neck pain was estimated to cost up to 7 man-years of lost productivity in this population per year.

Despite considerable attention in the 1990s to these neck problems being described in aircrew around the world, the problems continued into the next decade. In the United Kingdom (UK), a 2008 survey of Royal Air Force (RAF) aircrew revealed that 70% of 144 fast jet aircrew had experienced neck pain at some point in their flying career [21]. De Loose et al. [22] conducted a survey of 90 F-16 pilots from the Belgian Air Force and the Royal Netherlands Air Force, using the Dutch Musculoskeletal Questionnaire, and found the year-prevalence of regular or continuous neck pain to be 18.9%. According to a more recent survey of 71 Belgian F-16 pilots, the year prevalence of regular or continuous neck pain more than doubled and was 48.2% in 2015 [23]. In 2011, 95% of Australian fast jet aircrew and 83% of Danish Air Force pilots reported having experienced flight-related neck pain within the past year [24]. In 2012, 45% of Finnish Air Force pilots reported flight-related neck pain during the previous year [25], slightly more than reported by Hamalainen et al. [18] in 1994. Also in 2012, Wagstaff et al. [26] found that 72% of Norwegian fighter pilots had experienced neck pain in flight or shortly after flight, compared to 35% who had experienced back pain in flight. They also reported that the mean G level for acute incidents of in-flight pain was 6.7 G. Raynaud et al. [27] surveyed 311 French fighter aircraft personnel, and found that 60% had experienced neck pain associated with flying – 70% of those had experienced the pain during flight.

Recent reports from the high-performance fighter community include Royal Canadian Air Force (RCAF) and USAF pilots [28]. Of the 85 CF-188 and CT-155 pilots responding to a survey, 61.2% had significant neck pain in the previous 12 months, 94% of which was described as 'flight-related,' confirming that aircrew neck pain continues to be an active aeromedical concern. Mayes et al. [28] found that 69% of fighter pilots reported neck pain due to flying, and 63% reported pain in the previous 90 days, while Lindsey et al. [29] reported that 94% of pilots in an operational USAF squadron (F-16, F-22, F-35) reported neck pain worsened by flying, while 69% reported pain in the previous 90 days.

Hamalainen et al. [18], in an effort to identify which pilots were at higher risk of acute in-flight neck pain, followed a cohort of student pilots through 1 – 3 years of operational flying. He found that, although 37.9% of the pilots had experienced flight-related neck pain by the end of the study, none of the possible predictor variables correlated with pain (including height, weight, neck circumference, and exercise).

Several recent studies have focused on identifying risk factors for neck pain, rather than simply documenting the problem. Kang et al. [30] published an analysis of a 1000-subject survey database to look for predictors and correlates of neck pain/injury in the Korean Air Force. They found that the amount of high-G exposure correlated with frequency and severity of neck pain, but not the level of G.

Amidst the continuing evidence that neck pain and injury continue to occur in various aviation occupations, doubt has been cast on the reported risk factors and confounding variables – these concerns will be reviewed later in this report. However, there appears to be a consensus that pilots of high-performance aircraft are indeed at increased risk of neck problems. Harms-Ringdahl [31], in summarizing the outcome of a NATO-sponsored Technology Watch, concluded that flying high-performance aircraft has an adverse effect on the cervical spine of aviators, both acutely and long-term. Lawson et al. [9] studied a multinational aircrew cohort, and concluded that while the pilot profession overall was at higher risk of occupational neck pain syndromes, the strongest association was found in pilots of high-performance aircraft (onset rate = 3.91). Shiri et al. [11] conducted a critical review of the literature, affirming the relationship between neck pain and fighter pilots' exposure to the highest levels of +Gz.

One of the most obvious contributing factors to neck injury risk in fighter aircraft is the increased manoeuvrability of modern high-performance aircraft. It has been repeatedly noted and summarized in the 1994 NATO report [14], that reports of neck injuries have increased with the advent of modern fighter aircraft.

In 1988, the US Navy reported some of the early concerns with the new generation of highly manoeuvrable fighter aircraft [16], [32], based on flight surgeon experiences with the F/A-18 aircraft, citing neck injury rates of 19 to 74 %.

The advent of the F-16 single-seat fighter in the late 1970s, which was acquired by the air forces of several nations, generated numerous reports in the literature between 1989 and 1995. Biesemans et al. [33] reported that 13 of 30 surveyed Belgian F-16 pilots admitted to neck problems while flying, a higher rate than encountered when the pilots had previously flown the F-104 Starfighter. Also, Vanderbeek [34] observed that the F-16 was associated with more frequent and severe neck injury than lower G aircraft, such as the F-5. Reports from the Turkish Air Force, Belgian Air Force, and Royal Netherlands Air Force corroborate the concerns with the increased capabilities of the F-16 aircraft [35], [36].

One ergonomic difference in the design of the F-16 that could account for an increased risk of neck problems is the 30-degree reclined pilot seat, compared to the traditionally upright seats in other fighter aircraft. Coakwell et al. [37] discussed the effect of this posture on neck stress, concluding that increased muscular work, plus increased pressure on the intervertebral disks, could place F-16 pilots at higher risk for both acute and chronic neck injury.

In Japan, the addition of the F-15 Eagle to the Japan Air Self-Defense Force was associated with an increase in neck complaints [38]. Of the 129 surveyed F-15 pilots, 89% reported muscle pains related to flying, far more neck pain events than in the F-4 or F-1 aircraft.

In Poland, neck problems became more common with the acquisition of MiG-23 fighter aircraft. Talar et al. [39] reported 42% of pilots with neck pain, especially after low-altitude flights; the problem was increased with the introduction of the MiG-29 aircraft. Thirty percent of Russian fighter pilots flying the MiG-29 or Su-27 aircraft reported back pain, mostly in the neck region, and always after active head movement behaviours [40].

2.2.3 Neck Pain Patterns in Fast Jet Aircrew

It was recognised long ago that there were complex pathophysiological processes accounting for the neck-related symptoms and diagnoses seen in fast jet pilots [14]. Two clinical presentations are generally acknowledged – first, the acute injury, which may be isolated or recurrent, and second, the long-term or chronic, which may persist long after flying activities have ceased. This section will characterise the acute pain syndromes, and the chronic disorders will be reviewed later, although it is recognised that these categories overlap and interrelate.

2.2.3.1 Acute Injury

Acute G-related neck injury can range from minor muscle strain to serious cervical injury, including myofascial syndrome, spasmodic torticollis, compression fracture, acute disk herniation, spinous process fracture, and interspinous ligament tear [32], [41], [42], [43]. High-risk behaviours were identified, particularly the 'check-six' manoeuvre during > 8 G, and unexpected sudden acceleration [44], especially affecting non-flying aircrew. A classic example is the well-documented case of a flight surgeon, reported by Andersen [15], summarized in the 1994 AGARD report [14], and quoted below:

> *The flight surgeon was in the rear seat [of the F-16B] and had been in control of the aircraft for 10 minutes. After completing a series of basic aerobatic manoeuvres, he handed control over to the pilot in the front seat. He then relaxed and turned his head maximally to the left to look for an opponent aircraft. While his head was in this position, he was caught completely unaware by a sudden 8 G climbing turn. Radiological examination showed a separation of the spinous processes of C5-6 and equivocal evidence of a compression fracture of C6.*

The range of acute symptoms are well reviewed in the 1994 AGARD report [14]; the reader is also referred to the thorough review of anatomy, geometry, correlated with the reported range of symptoms [37]; prevention and treatment considerations are reviewed in Chapter 4.

More recent reports of acute neck problems in fighter pilots do not present new symptom complexes, but have sought to identify contributing factors that might help in designing preventive programmes. For example, Tucker et al. [45] identified a correlation between post-flight recovery time and weekly hours of deskwork. Duvigneaud et al. [46] recently studied Belgian Air Force student pilots, and found a 22% prevalence of neck pain, which correlated with average flight duration, low back pain, weight, and maximal isometric strength for left and right lateral flexion.

One additional factor contributing to the risk of neck pain in fast jet pilots deserves mention. The flight helmet has evolved beyond a protective device to also serving as a platform for flight-related equipment. As more technology is attached to the helmet, any acceleration-related stress on the neck is magnified by the increased weight and centre-of-gravity effects. These factors are reviewed in Chapter 5, but the lessons should be clear to the fixed-wing aerospace medicine community as well. For example, the implementation of the Joint Helmet-Mounted Cuing System (JHMCS) for fighter aircraft has dramatically increased neck-related symptoms. One survey of Danish fighter pilots found that 97% of pilots using JHMCS experienced neck pain in flight or shortly after flying [47], and a recent study of USAF fighter pilots showed that neck pain was significantly worse with JHMCS, and with a prior history of neck problems [48].

2.2.3.2 Long-Term Effects of Acute Injury

There is no question that exposure to high levels of G encountered in fighter aircraft can cause acute neck injuries of various types. It is less clear, however, whether fighter pilots are at higher risk of chronic neck injury or long-term effects of their acute injuries becoming manifest later in life. This has been the focus of three separate NATO panels and innumerable publications in the aeromedical literature, with generally ambiguous results. This section will summarize the previous reviews and provide additional references to update the accumulated knowledge and consensus.

First, a brief consideration of the problems clouding the literature is appropriate. Assessing the chronic effects of any lifetime factor hinges on two factors – reliably detecting the effect, and separating the effect from inevitable confounding factors, the greatest of which is aging. With respect to our current concern, cervical injury and degeneration, researchers have access to an array of sensitive imaging tools, including conventional x-ray, computed tomography, nuclear medical imaging, Magnetic Resonance Imaging (MRI), and ultrasound. Each has advantages and disadvantages, but as the ability to define the anatomy and physiology has evolved, the possibility of false-positive type I errors with newer imaging techniques demands a carefully selected control group [49]. In particular, separating unrecognised aging effects from occupational effects is difficult. Matsumoto et al. [50] found disk degeneration in 17% of asymptomatic men in their twenties, and 86% of men over 60. Brinjikji et al. [51] reviewed 33 articles reporting imaging findings for 3110 asymptomatic individuals, and reported the prevalence of disk degeneration in 20-year-olds as 37%, disk bulges 30%, and disk protrusion 29%.

Over the past 30 years, various neck pathologies have been documented in high-performance fixed-wing aircrew, and may well represent chronic changes; however, establishing that sustained acceleration is the cause of a specific injury is problematic. Chronic changes documented in the aeromedical literature include degenerative arthritis, disk protrusion, disk degeneration, osteophytes, and kyphosis, among others. Two NATO Panels concluded that there was sufficient evidence that flying high-performance aircraft has an adverse effect on the cervical spine of aviators [52], [53]; a conclusion supported by a 2015 meta-analysis [54]. However, another recent meta-analysis concluded that exposure to the highest levels of G forces were associated with a higher prevalence of neck pain [11]. The authors of the meta-analysis criticized previous studies for failing to control for age and other known confounders, concluding that, “Fighter pilots exposed to high G forces may be at a greater risk for neck pain than those exposed to low G forces.” Nonetheless, there is a weight of applied research describing neck pathology in pilots of high-performance aircraft, with control subjects that will be noted.

One of the first reports suggesting long-term effects of high-performance aircraft exposure on aircrew health was Hamalainen et al. [18]. Twelve senior pilots were compared to age-matched non-flying controls and were found to have significantly more disk degeneration in C3-C4, and slightly more degeneration at the C4-C5 level.

In 1995, Kikukawa et al. [38] found that Japan Air Self-Defense Force F-15 pilots with a history of acute neck pain had more degenerative changes of the cervical spine. In 1999, Rios-Tejada et al. [55] studied 24 Spanish Air Force fighter pilots with x-ray and MRI, and found an increase in C4-C5 intervertebral disk degeneration, and significant vertebral pathologies in C5-C6, compared to a cargo pilot control group.

Burns et al. [56] examined 22 asymptomatic male G research subjects who had significant exposure to high-level sustained Gz, and compared their spinal MRI to 19 age and sex-matched controls. Although abnormalities were found in 91% of the centrifuge subjects, 79% of control subjects had abnormal findings. Further, within-reader and between-reader variability was very high; even after a second reader panel was recruited, disagreement was still high (56%), reducing confidence in the interpretation of scans in a clinical environment.

Hendricksen and Holewijn [57] compared cervical spine x-rays from 188 Dutch F-16 pilots with 128 controls to assess possible spine degeneration. Subjects had at least two radiographs taken an average of 6 years apart, and the radiologists were blinded as to study group. The F-16 pilots were found to have more osteophytic spurring at C4-C5, and C6-C7, but as the controls were younger, age could not be ruled out as a factor.

Swedish researchers compared neck MRI scans from 16 male fighter pilots (mean age of 42 years of age and 2600 flying hours), and 15 age-matched controls without military flying experience. The experienced pilots had more osteophytes, disk protrusions, cord compressions, and foraminal stenoses than the age-matched controls. A separate group of young pilots had much fewer degenerative lesions [58].

Five years later, Petren-Mallmin and Linder [59] followed up the subjects from the 1994 MRI study to assess any changes in cervical spine degenerative changes. Compared to the original MRI scans, there was a significant increase in disk protrusions in both pilots and controls, in osteophytes in controls, and foraminal stenosis in experienced pilots. The authors suggested that military high-performance aircraft pilots were at an increased risk of early development of degenerative lesions that are normally seen in an aging population; and that the differences between pilots and controls grew less over time, with aging.

Recently, Korean Air Force pilots, who are known to suffer high rates of neck pain, were studied to determine risk factors and radiological correlates [60]. Sixty-three Air Force pilots were examined radiographically and were divided into neck pain (n = 32) and no neck pain (n = 31) groups. No differences in age, Body Mass Index (BMI) or exercise patterns were found between the neck pain groups, but fighter pilots had more neck pain. Those with neck pain had more kyphotic changes in the cervical spine, suggesting that fighter pilots might be at higher risk of cervical alignment problems.

2.2.4 Summary of High-Performance Fighter Aircraft Literature

The aviation-centric studies cited above provide targeted evidence supporting the case for an elevated risk of neck pathology in pilots of high-performance fighter aircraft. This evidence must be weighed in view of compelling epidemiological evidence that other factors contribute to neck problems in aircrew. The fact remains that neck pathology occurs in the aviation population, leaving aerospace medicine professionals with the challenge of preventing and treating these disorders, regardless of the cause, while determining safe aeromedical dispositions for the involved aircrew.

2.2.5 Neck Pain and Injury in Fixed-Wing Transport Aircraft

Fixed-wing transport aircraft tend to present a low-risk aircrew environment with respect to neck pain and injury compared to other airframes, yet in a broad, multinational multi-airframe survey, pilots of long-haul cargo/passenger airframes displayed an increased risk of neck pain symptoms [9][2]. These problems are possibly related to prolonged postures and vibration in the cabin environment compared to non-flying professions that have similar long sitting hours. Loomis et al. [61] found that 78% of pilots and 74% of Naval Flight Officers flying the E-2C Hawkeye turboprop fixed-wing aircraft reported neck and/or back pain during the preceding year. The most common symptom was an in-flight dull ache, lasting 24 – 48 hours. Having enumerated these two studies, the aeromedical literature does not offer further evidence for a widespread neck pain problem in fixed-wing transport aircraft crews.

2.2.6 Neck Pain and Injury in Helicopters

As discussed above, neck problems are relatively new to helicopter aircrew, who are classically associated with low back pain problems, variously attributed to helicopter-unique factors such as vibration, posture, etc. Neck pain reports began to appear in the 1990s, coincidentally as the use of helmet-mounted devices increased in military rotary-wing aviation. These clinical reports will be reviewed, followed by a more intensive summary of the head-supported mass problems.

In a detailed report of back pain characteristics in Australian helicopter pilots, Thomae et al. [62] found a 29% one-year prevalence of neck pain associated with flight (n = 131), noting that a combination of helmet weight and a hyperextended neck posture may be responsible.

Äng and Harms-Ringdahl [63] studied 127 Swedish helicopter pilots, finding a 57% 3-month prevalence of neck pain, with 32% reporting frequent pain. In the UK RAF, 57% of 188 helicopter pilots admitted to flight-related neck pain, which was significantly correlated with accumulated flight hours [21]. Military helicopter pilots in the Royal Netherlands Air Force and Navy were surveyed (n = 113), and reported a one-year prevalence of 43%, and 20% admitted to regular or continuous neck pain [64]. Sharma and Agarwal [65] surveyed 55 Indian military helicopter pilots who flew the Mi-8 (n = 31) or the Mi-17 (n = 24), and found 19% and 22% complaining of neck pain, respectively.

In a survey of deployed US Army aircrew, Hiatt and Rash [66] found that 62% (41/66) of aircrew admitted to at least ‘occasional’ neck pain, and 30% (20/66) described neck pain ‘frequently’ or ‘always’ during flight, which was frequently attributed to the heavy use of night vision goggles (reviewed in Chapter 5). Another survey found 58% (44/77) of Army aircrew reporting neck pain while flying; respondents with smaller sitting height, fewer flying hours, and heavier NVG counterbalance weight reported less neck pain [67].

As concern was building around the international military helicopter community, significant problems arose in the Canadian military. Large scale RCAF helicopter aircrew surveys in 2004 (n = 281) and 2014 (n = 215) documented neck trouble prevalence of 80% and 75%, respectively, equally amongst pilots and Flight Engineers (FE) [8] [68]. In a smaller sample of 40 Canadian aircrew, Harrison et al. [69] found a 53% prevalence of neck pain in both helicopter pilots and flight engineers. The similarity in results suggested that the cause of the pain was something common to front and rear crew. While neck pain complaints were similarly high in these helicopter occupational groups, Farrell et al. [70] highlighted different causal mechanisms in pilots (i.e., quasi-static non-neutral positions) compared to flight engineers (i.e., extreme postures), which would lead to different, crew-specific solutions.

[2] Belgium Air Force F-16 pilots with neck and/or back pain are often converted to Transport aircraft or helicopters because of the low risk. Some of the Transport pilots may still report neck or lower back pain. Thus, it is important to request information on aircraft previously flown.

Using a comprehensive multivariate approach to determine important risk factors for neck pain, Harrison et al. [71] analysed questionnaire data from 40 aircrew detailing lifetime prevalence of neck pain, flight history, physical fitness results, and physiological variables, plus physiological performance variables in Canadian aircrew. A logistic regression resulted in a simple equation that included two variables: the longest single NVG mission, and aircrew member height. The equation was successfully validated using half of the sample; the author suggested that the equation "could be used by global operational units" to help assess the likelihood of aircrew neck pain. However, Chafé and Farrell [8] found no significant differences in height between 52 aircrew with no neck trouble and 161 aircrew with self-reported lifetime prevalence of neck pain. In a study of 88 US Army aircrew, Walters et al. [67] found an association between higher sitting height and neck pain – these problems could be exacerbated by specific aircraft cabin limitations. Further study is required to determine the relationship between neck pain, anthropometry, and ergonomics.

Israeli helicopter pilots (n = 566) were studied by Grossman et al. [72], who found utility helicopter pilots to have a higher rate of neck pain (47.3%) compared to attack helicopter pilots (36.4%). A significant proportion of subjects suffered from pain in multiple regions, particularly among utility helicopter pilots (32.74%). Severity of pain was graded higher in all three regions (cervical, mid, and lower back) in utility helicopter pilots, who also had more prevalent and more severe back pain than pilots of other platforms.

UK Apache attack helicopter pilots were followed over a 10-year period, as part of a joint US-UK study primarily aimed at detecting possible effects of the Apache's monocular display on vision. Other questionnaire data collected during the study revealed that the percentage of aircrew experiencing in-flight neck pain rose over the course of the study from 30% to approximately 57% in both the Apache study group and the non-Apache control helicopter group [73].

Orsello et al. [74] used data from a 2011 survey of 458 US Navy helicopter aircrew (81% of whom were H-60 pilots) to determine predictors and risk factors for neck pain. Fifty-eight percent of the respondents reported significant in-flight neck pain; the strongest predictor of in-flight neck pain was having low back pain during flight. Pilots having low back pain during at least 50% of the flight duration were 7 times more likely to suffer from significant neck pain in-flight. Other factors, including height, BMI, and total flight hours did not predict in-flight neck pain.

van den Oord [75] collected survey data and physiological data from Royal Netherlands Air Force helicopter crew, finding a 20% one-year prevalence of regular or continuous neck pain, slightly lower than in previous reports. Muscular strength, range-of-motion, and neck position sense were not correlated with a history of neck pain.

The comprehensive survey of RCAF helicopter crews, mentioned earlier, focused on the problems with the CH-146 Griffon helicopter, which has accounted for some of the highest neck pain rates ever documented [8]. This survey documented a 75% lifetime prevalence (162/215) of in-flight neck trouble; their responses showed that flight hours, NVG usage, and awkward tasks and postures worsened neck pain.

A multinational survey of helicopter aircrew neck pain was conducted by researchers from the UK, US Army, US Navy, and Canada, found that 45% of 1,541 aircrew reported neck pain during flight, and 85% reported at least one episode of neck pain during flight [76].

Nagai et al. [77] studied the flexibility of 115 US Army helicopter crew, and found that OH-58 Kiowa Scout aircrew had reduced joint flexibility at multiple measured sites, including neck flexion, extension, and rotation, compared to UH-60 Black Hawk aircrew. They speculated that this might predispose OH-58 crews to neck pain and low back pain and could lead to targeted countermeasures.

Most recently, Crowley et al. [78] conducted a review and epidemiologic study, using a retrospective cohort design, comparing 3,601 US military helicopter pilots to control groups of fixed-wing pilots and maintenance officers during the period 1995 – 2015. Overall, the helicopter pilots were not at increased risk of neck problems, but in a sub-analysis, USAF helicopter pilots were found to have a 27% higher risk of neck strains/sprains than USAF fixed-wing pilots.

2.2.6.1 Rear Aircrew Issues

Although the bulk of the research has focused on front cabin pilot crew, there is increasing concern about the rear crew – loadmasters, crew chiefs, etc., whose physical workload, musculoskeletal requirements, and neck loads are greater [47]. 65% of Canadian CH-146 flight engineers reported neck pain, for example. Studying Dutch Defence Helicopter Command rear aircrew, van den Oord et al. [79] found one-year prevalence of 62% for any neck pain, and 28% for regular and continuous neck pain. These results compare to a 71% career prevalence for British military helicopter rear aircrew [21]. Rear aircrew are clearly at risk for neck pain and pathology.

2.2.6.2 Long-Term Effects

As is the case with fast jet aircrew, there have been numerous studies in recent years, examining possible long-term effects of neck pain in helicopter aircrew. This research is vulnerable to the same problems, namely being able to detect the chronic effect of interest – through medical imaging – and separating the effect from confounding factors, e.g., aging.

Aydoq et al. [80] analysed conventional x-rays for 732 Turkish pilots, including 159 helicopter pilots, 19% of whom had cervical changes – higher than in the other pilot groups or the control group. Age was the most important variable related to spondylarthritic or spondylitic changes.

Landau et al. [81] compared cervical MRI findings among fast jet, helicopter, and transport aircraft pilots, and found that spinal degenerative changes seemed to be more linked to age than the flight platform. Since the groups were very small (10 pilots each), and age was not controlled, the effects of age and platform could not be analysed.

Byeon et al. [82] studied 186 Korean helicopter pilots and a clerical control group with radiographs, interviews, and questionnaires, and found that degenerative changes were significantly more prevalent in the helicopter pilot group. In a multivariate model, accumulated flight hours were associated with degenerative changes.

Most recently Knox et al. [83] analysed the US Defense Medical Epidemiological Database (DMED) for cases of lumbar disc herniation in military helicopter pilots from 2006 – 2015, and found the incidence to be significantly higher than in a control group comprised of all non-helicopter pilot officers in the US military. This effect was particularly strong in Army helicopter pilots, who had an incidence rate more than that of Navy and Marine Corps helicopter pilots.

2.2.6.3 Summary of Helicopter Literature

In summary, neck pain in helicopter pilots have surfaced over the past two decades, across rotary-wing platforms and nations. The reported rates appear reasonably uniform, in the 20 – 80 % prevalence range, depending on the statistic used, and have persisted, unchanged, over the past decade. Whereas neck problems in fast jet pilots are usually linked to high +Gz exposure, the neck problems in rotary-wing crews seem to be more linked to weight added to the head/helmet complex, and the awkward tasks and postures performed during flight.

2.3 AIRCREW NECK PAIN DEFINITION

2.3.1 Defining Pain

A universally accepted definition for pain is difficult to obtain. This is largely due to the fact that the pain will be characterised by the mechanism of injury and that the perception of pain varies greatly from one individual to another. The most commonly referenced definition for pain is that of the International Association for the Study of Pain (IASP), who define pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage. Pain is always subjective" [84]. The World Health Organization defines pain as "an unpleasant sensory or emotional experience associated with actual or potential tissue damage, or described in terms of such damage."

2.3.2 Defining Neck Pain

When we consider the relevance to this group, we can further refine the definition. The IASP go on to define cervical spinal pain as 'pain perceived anywhere in the posterior region of the cervical spine, from the superior nuchal line to the first thoracic spinous process' [85]. Note that pain is always subjective and a sensation in a part or parts of the body, but it is also always unpleasant and therefore also an emotional experience. This definition can be further delineated between upper cervical spinal pain and lower cervical spinal pain, above or below an imaginary transverse line through C4 [86].

Guzman et al. [87] recommend a clinical classification in four grades, according to the 'severity of pain':

- **Grade I:** Neck pain with no signs of major structural pathology and no or minor interference with activities of daily living.
- **Grade II:** Neck pain with no signs or symptoms of major structural pathology but major interference with activities of daily living.
- **Grade III:** Neck pain with no signs or symptoms of major structural pathology but with neurologic signs of nerve compression.
- **Grade IV:** Neck pain with signs of major structural pathology.

Common symptoms of neck pain include radiculopathy, myelopathy, and altered Range of Motion (ROM). Neck pain in the absence of radiculopathy, myelopathy, or clear serious underlying disease is also called mechanical neck pain; the pathophysiology of this condition remains difficult to understand [88].

2.3.3 Defining Chronic Pain

Establishing a clear definition of timing of pain is important in order to categorize the problem and act accordingly.

Broadly speaking, chronic pain is a prevalent problem with significant costs to individuals, significant others, and society [89]. There exist a number of different timing classifications in the literature. The IASP defines acute neck pain as that experienced for less than seven days, sub-acute neck pain as that experienced for more than seven days but less than three months and chronic neck pain as that experienced for three months or more [90].

The Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders use a very similar definition of duration of neck pain, although the terminology is slightly different[3] [91].

It is generally accepted that the limit between "acute" and "chronic" pain is three months, and the majority of physiotherapists use the classification from IASP. In fact, it has been shown that there are differences in behaviour, risk factors, effective treatments, and prognosis of patients when you consider periods greater than three months. Development of chronic disability is one of the major concerns in the management because of its great social costs. Although it is likely that the risk for chronicity increases constantly as long as pain lasts, the rationale for distinguishing "sub-acute" from "acute" patients is to detect those at a higher risk for chronic disability early and to apply measures for reducing that risk. Early detection is important because chronicity is a bad prognosis factor for disability [92].

It is therefore recommended that acute is defined as up to seven days, sub-acute as seven days to three months and chronic as neck pain lasting greater than three months.

2.3.4 Flight-Related Neck Pain

When we consider the complexity of the issues surrounding neck pain, and the difficulty in finding a solution, it is important to find definition of pain that relates to flight. This definition should put into context the issue and impact on capability for decision makers and to allow for comparison of data sets. Results of different survey studies are often not comparable because of using (slightly) different questions and outcome measures.

The war fighter has an inherently difficult job, which will undoubtedly be uncomfortable in the extremes, but when this discomfort moves from the extremes to every day, then there are capability concerns that need to be addressed.

Within NATO HFM-252 RTG, consensus has been reached about the definition of significant neck pain and flight-related neck pain and is used within this report, adapting the terminology first used by the Royal Australian Air Force (RAAF) [20]:

- **Significant Neck Pain –** refers to the presence of discomfort that intrudes into aircrew awareness during usual activities, and causes them to perform at a lower level, continue despite discomfort, or modify their activity to reduce the discomfort. It *does not* refer to trivial mild aches that are easily dismissed and do not affect function.
- **Significant Flight-Related Neck Pain –** refers to significant neck pain that occurs during or within 48 hours after flight. It *does not* refer to pain that is obviously due to other activities or causes.

It is difficult to define the point at which the aviator is no longer fit for unrestricted active flight duty. Each individual will have different tolerance to pain, so the point at which it becomes 'significantly distracting' will vary considerably. The clinician's level of experience with neck pain will vary as well and this will impact the management of the aviator's flight status.

The decision to impose employment limitations (including grounding) is the responsibility of the aviation medicine provider but this is often the result of collaboration between provider and patient. Things to consider are included in Chapter 4.

[3] 1) transitory is neck pain lasting < seven days, 2) short-duration neck pain lasting longer than seven days but less than three months, and 3) long-duration neck pain that lasts three months or longer.

2.4 OPERATIONAL IMPACT OF AIRCREW NECK PAIN AND INJURY

2.4.1 Pain and Performance

When considering employment limitations in Section 2.3.4 above, the potential impacts or consequences of in-flight neck pain on performance were listed. As a result of any or all of the in-flight neck pain, operators can be distracted from critical cockpit tasks by shifting attention. As a result, critical alarms inside the cockpit or objects outside of the cockpit may be missed or not attended to in time.

Controlled research into the effects of pain on human performance is rare primarily for ethical and methodological reasons. The objective of most clinical pain research tends to focus on the patient reducing or adapting to pain, as an endpoint, rather than assessing the occupational effects of persistent pain. The literature reveals complex relationships among pain attributes and performance effects.

For instance, Moore et al. [93] studied the effect of chronic pain on task performance, and concluded that sustained attention performance is diminished while mental flexibility, planning, and inhibition appear to be intact. Headache pain, on the other hand, appears to impair general task performance, irrespective of task complexity, rather than specific attentional mechanisms [94]. Headache pain has an effect on the cognitive components necessary for the successful completion of tasks – particularly complex tasks that require focus and the processing of multiple cues [93].

Pain has also been shown to affect working memory [95] and sustained attention, while other cognitive abilities seem relatively resistant to pain [96].

Observation and anecdotal evidence support the research results – operator performance is affected by pain, and in complex ways [97]. It is likely that aircrew in pain would have trouble attending to aviation duties, especially complex tasks requiring sustained attention to complete the mission safely [98]. Probert et al. [98] observed flight-task performance decrements with acute pain stimuli, but only for less experienced aircrew.

Most neck problems do not result in loss of flight status [99], but temporary grounding frequently occurs [8], [16], [19], [28], [100]. Because neck pain is so common, even a small proportion of prevalent cases results in large numbers of affected aircrew, with real operational impact.

In high-performance fighter aircraft, acute neck pain can be severe. Stupakov et al. [40] reported 6.3% of pilots' neck pain was "so extremely painful that it reduced their combat readiness and flying safety." Clark [41] reported a case of G-related spasmodic torticollis, which obviously would affect a pilot's ability to fly safely. Almost half the F/A-18 pilots reported by Newman [19] stated their neck injury interfered with mission completion. One-fourth of E-2C US Navy pilots reported limitation of their flying performance due to neck pain [61]. Decreased range-of-motion is frequently reported in fighter pilots with neck problems [35], often affecting pilots' ability to 'check-six' [29], [100], [101]. Mayes et al. [28] found that 78% of USAF fighter pilots reported that neck pain had adversely affected their mission.

Helicopter pilots typically have slower pain onset, but can ultimately end up with severe pain [8], [68], which interferes with safe aircraft operation [63]; Walters et al. [67] reported that 30% of sampled US Army helicopter pilots had experienced severe or incapacitating pain during flight, while 20% felt that their neck pain affected their ability to perform mission-related tasks. Decreased range-of-motion is frequently seen in helicopter pilots with neck pain [64], [102]. Orsello et al. [74] reported that in a group of aircrew with neck pain, 41% had experienced related loss of situation awareness.

The combination of controlled studies, aircrew surveys, and anecdotal evidence, supports the conclusion that the performance of aircrew suffering from acute or chronic neck pain is degraded.

2.5 RECOMMENDATIONS

Recommendation 2.1 (Section 2.3): This chapter has defined a series of terms that facilitate data collection and comparison across studies, which will enhance the ability to address the issues going forward. These definitions of a) Acute Pain; b) Sub-Acute Pain; c) Chronic Pain; d) Significant Pain; and e) Significant Flight-Related Pain should be used consistently when collecting data about neck pain.

2.6 REFERENCES

[1] Cohen, S.P. (2015). Epidemiology, diagnosis, and treatment of neck pain. Mayo Clin Proc, 90(2), 284-299. doi: 10.1016/j.mayocp.2014.09.008.

[2] Fejer, R., Kyvik, K.O., and Hartvigsen, J. (2006). The prevalence of neck pain in the world population: A systematic critical review of the literature. European Spine Journal, 15, 834-848.

[3] Cote, P., van der Velde, G., Cassidy, J.D., Carroll, L.J., Hogg-Johnson, S., Holm, L.W., et al. (2008). The burden and determinants of neck pain in workers: Results of the Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders. Spine (Philadelphia, PA, 1976), 33(4 Suppl), S60-74. doi: 10.1097/BRS.0b013e3181643ee4.

[4] Cote, P., Cassidy, D.J., Caroll, L.J., and Kristman, V. (2004). The annual incidence and course of neck pain in the general population: A population-based cohort study. Pain, 112, 267-273.

[5] Gross, A., Forget, M., St. George, K., Fraser, M.M.H., Graham, N., Perry, L., … Brunarski, D. (2012). Patient education for neck pain (review). Cochrane Database of Systematic Reviews (Vol. 2012): The Cochrane Collaboration, John Wiley and Sons, Ltd.

[6] Harrison, M.F., Coffey, B., Albert, W.J., and Fischer, S.L. (2015). Night vision goggle-induced neck pain in military helicopter aircrew: A literature review. Aerospace Medicine and Human Performance, 86(1), 46-55.

[7] Xiao, A., and Farrell, P.S.E. (2016). Royal Canadian Air Force neck- and back-trouble research: A historical review: Reference Document, DRDC-RDDC-2016-D031, Defence Research and Development Canada, Toronto, Canada.

[8] Chafé, G.S. and Farrell, P.S.E. (2016). Royal Canadian Air Force CH-146 Griffon aircrew 2014 spinal musculoskeletal trouble survey. DRDC-RDDC-2016-R179, Defence Research and Development Canada, Toronto, Canada.

[9] Lawson, B.K., Scott, O., Egbulefu, F.J., Ramos, R., Jenne, J.W., and Anderson, E.R. (2014). Demographic and occupational predictors of neck pain in pilots: Analysis and multinational comparison. Aviat Space Environ Med, 85(12), 1185-1189. doi: 10.3357/ASEM.4077.2014.

[10] Rice, G.M., and Rizo, E.B. (2015). The descriptive epidemiology of neck pain in DoD aviators. Aerospace Medicine and Human Performance, 86, 192.

[11] Shiri, R., Frilander, H., Sainio, M., Karvala, K., Sovelius, R., Vehmas, T., and Viikari-Juntura, E. (2015). Cervical and lumbar pain and radiological degeneration among fighter pilots: A systematic review and meta-analysis. Occup Environ Med, 72(2), 145-150. doi: 10.1136/oemed-2014-102268.

[12] Pippig, T.M. (2008). Review of the German national work programme on the long-term effects of sustained high G on the cervical spine. NATO RTO Review of National Work Programmes on the Long-Term Effects of Sustained High G on the Cervical Spine. Neuilly-sur-Seine, France: NATO RTO.

[13] Phillips, C. (1959). Central nervous system injury from high radial G-force. The musculoskeletal and vestibular effects of long-term repeated exposure to sustained high-G, pp. 847-851. Neuilly-sur-Seine, France: NATO AGARD.

[14] AGARD. (1994). Advisory Group for Aerospace Research and Development (AGARD): The musculoskeletal and vestibular effects of long-term repeated exposure to sustained high-G. Neuilly-sur-Seine, France: NATO RTO.

[15] Andersen, H.T. (1988). Neck injury sustained during exposure to high-G forces in the F16B. Aviat Space Environ Med, 59(4), 356-358.

[16] Knudson, R., McMillan, D., Doucette, D., and Seidel, M. (1988). A comparative study of G-induced neck injury in pilots of the F/A-18, A-7, and A-4. Aviat Space Environ Med, 59(8), 758-760.

[17] Vanderbeek, R.D. (1989). Prevalence of G-induced cevical injury in USAF pilots GARD-CP-471, Conference Proc. Neck injury in advanced military aircraft environments. Neuilly-sur-Seine, France: NATO RTO.

[18] Hamalainen, O., Vanharanta, H., and Bloigu, R. (1994). +Gz-related neck pain: A follow-up study. Aviat Space Environ Med, 65(1), 16-18.

[19] Newman, D.G. (1997). +GZ-induced neck injuries in Royal Australian Air Force fighter pilots. Aviat Space Environ Med, 68(6), 520-524.

[20] Smith, A.M. (2016). The prevalence and operational significance of neck pain and back pain in Air Combat Group: IAM-2016-003-CR, Institute of Aviation Medicine – Adelaide, Adelaide, Australia.

[21] Greeves, J., and Wickes, S. (2008). Review of the United Kingdom national work programme on the long-term effects of sustained high G on the cervical spine. NATO RTO Review of National Work Programmes on the Long-Term Effects of Sustained High G on the Cervical Spine. Neuilly sur Seine, France: NATO.

[22] De Loose, V., Burnotte, F., Cagnie, B., Stevens, V., and Van Tiggelen, D. (2008). Prevalence and risk factors of neck pain in military office workers. Mil Med, 173(5), 474-479.

[23] Duvigneaud, N., Emonds, D., Bagaianu, D., van den Oord, M., and Van Tiggelen, D. (2016). Neck and back pain among BAF F-16 pilots. Paper presented at the Ramstein Aerospace Medicine Summit, Ramstein, Germany.

[24] Netto, K., Hampson, G., Oppermann, B., Carstairs, G., and Aisbett, B. (2011). Management of neck pain in Royal Australian Air Force fast jet aircrew. Mil Med, 176(1), 106-109.

[25] Honkanen, T., Mantysaari, M.J., Leino, T.K., and Siitonen, S. (2012). Prevention and management of neck and low back pain among the Finnish Air Force pilots. Paper presented at the Aerospace Medical Association, Atlanta, GA.

[26] Wagstaff, A.S., Jahr, K.I., and Rodskier, S. (2012). +Gz-induced spinal symptoms in fighter pilots: Operational and individual associated factors. Aviat Space Environ Med, 83(11), 1092-1096.

[27] Raynaud, F., Dussault, C., Monin, J., Perrier, E., Coulmann, N., and Coste, S. (2017). Neck pain prevalence on French fighter aircraft crew: Observational study among 311 flying crew members. Aerospace Medicine and Human Performance, 88, 257.

[28] Mayes, S.R., Turner, A., Clap, B., Reed, B.H., and Ennis, E. (2018). Epidemiologic assessment of neck pain in USAF fight pilots. Paper presented at the Aerospace Medical Association, Dallas, TX.

[29] Lindsey, M.H., Anderson, B., Turner, A., and Kaiser, J. (2018). 5th Generation specific fighter neck pain concerns: Ergonomics and mission impact. Paper presented at the Aerospace Medical Association, Dallas, TX.

[30] Kang, S., Hwang, S., Lee, E.T., Yang, S., and Park, J. (2011). Measuring the cumulative effect of G force on aviator neck pain. Aviat Space Environ Med, 82(11), 1042-1048.

[31] Harms-Ringdahl, K. (2008). Review of National Work Programmes on the Long-Term Effects of Sustained High G on the Cervical Spine. Neuilly-sur-Seine, France: NATO RTO.

[32] Yacavone, D.W., and Bason, R. (1992). Cervical injuries during high G maneuvers: A review of Naval Safety Center data, 1980 – 1990. Aviat Space Environ Med, 63(7), 602-605.

[33] Biesemans, I., Ingels, M., and Vanderbosch, P. (1989). A survey of cervical pain in pilots of a Belgian F-16 air defense wing. Paper presented at the Neck Injury in Advanced Military Aircraft Environments, Neuilly-sur-Seine, France: NATO RTO.

[34] Vanderbeek, R.D. (1988). Period prevalence of acute neck injury in U.S. Air Force pilots exposed to high G forces. Aviat Space Environ Med, 59(12), 1176-1180.

[35] De Loose, L., Van den Oord, M., Burnotte, F., Van Tiggelen, D., Stevens, V., Cagnie, B., … Danneels, L. (2008). Individual work- and flight-related issues in F-16 pilots reporting neck pain. Aviation, Space, and Environmental Medicine, 79, 779-783.

[36] Turbedar, E., Yilmaz, U., Alan, M., Buyukcakir, C., Sarilayalar, U., and Savasan, M. (1999). Spinal injury in Turkish fighter pilots. Cervical spinal injury from repeated exposures to sustained acceleration, pp. 29-30. Neuilly-sur-Seine, France: NATO RTO.

[37] Coakwell, M.R., Bloswick, D.S., and Moser, R. (2004). High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviation, Space, and Environmental Medicine, 75, 68-80.

[38] Kikukawa, A., Tachibana, S., and Yagura, S. (1995). G-related musculoskeletal spine symptoms in Japan Air Self-Defense Force F-15 pilots. Aviat Space Environ Med, 66(3), 269-272.

[39] Talar, J., Mazurek, K., Klukowski, K., Kwasucki, J., Marek, J., and Stepien, A. (1999). Review of the vertebral column pain problems in Polish pilots: Cervical injury from repeated exposures to sustained acceleration. Neuilly sur Seine, France: NATO RTO.

[40] Stupakov, G.P., Khomenko, M.N., Bukhtiyarov, I.V., and Vasilyev, A.Y. (2008). Pathological and functional changes of the spinal column in Russian pilots of high-performance aircraft. NATO RTO Review of National Work Programmes on the Long-Term Effects of Sustained High G on the Cervical Spine. Neuilly-sur-Seine, France: NATO RTO.

[41] Clark, J. (1990). Cervical dystonia following exposure to high-G forces. Aviation, Space, and Environmental Medicine, 61, 935-937.

[42] Mestre-Moreiro, M., Caflizal-Garcia, M., Barcena-Orbe, M., and Rios-Tejada, F. (1988). Cervical herniation in fighter pilots. Paper presented at the Reunion Hispano lusa de Neurocigugia, Lisbon, Portugal.

[43] Schall, D.G. (1989). Non-ejection cervical spine injuries due to +Gz in high-performance aircraft. Aviat Space Environ Med, 60(5), 445-456.

[44] Green, N.D. (2003). Acute soft tissue neck injury from unexpected acceleration. Aviation Space and Environmental Medicine, 74, 1085-1090.

[45] Tucker, B., Netto, K., Hampson, G., Opperman, B., and Aisbett, B. (2012). Predicting neck pain in Royal Australian Air Force fighter pilots. Military Medicine, 177(4), 444-450.

[46] Duvigneaud, N., Bellen, C., and Pattyn, N. (2019). Individual, work and flight-related factors that might lead to an outcome of neck and low back pain in military student pilots. Paper presented at the RAMS and STO Technical Course, Garmisch-Partenkirsch, Germany.

[47] Netto, K., and Burnett, A. (2011). Neck muscle activation in helicopter loadmasters during intensive nightflight operations. Paper presented at the International Society of Biomechanics, Brussels, Belgium.

[48] Chumbley, E.M., Stolfi, A., and McEachen, J.C. (2017). Risk factors for cervical pain in F-15C pilots. Aerosp Med Hum Perform, 88(11), 1000-1007. doi: 10.3357/AMHP.4848.2017.

[49] Jensen, M.C., Brant-Zawadski, M.N., Obuchowski, N., Modic, M.T., Malkasian, D., and Ross, J.S. (1994). Magnetic resonance imaging of the lumbar spine in people without back pain. New England Journal of Medicine, 331, 69-73.

[50] Matsumoto, M., Fujimura, Y., Suzuki, N., Nishi, Y., Nakamura, M., Yabe, Y., and Shiga, H. (1998). MRI of cervical intervertebral discs in asymptomatic subjects. J Bone Joint Surg Br, 80(1), 19-24.

[51] Brinjikji, W., Luetmer, P.H., Comstock, B., Bresnahan, B., Chen, L., Deyo, R., … Jarvik, J. (2015). Systematic literature review of imaging features of spinal degeneratino in asymptomatic populations. American Journal of Neuroradiology, 36, 811-816.

[52] NATO. (1999). North Atlantic Treaty Organization (NATO): Cervical spine injury from repeated exposure to sustained acceleration. RTO-TR-4 AC/323(HFM)TP/9, Neuilly-sur-Seine, France.

[53] NATO. (2008). North Atlantic Treaty Organization (NATO): Review of National Work Programmes on the Long-Term Effects of Sustained High G on the Cervical Spine: TRO-TR-HFM-083. Neuilly-sur-Seine, France: NATO.

[54] Kollock, R., Games, K., Wilson, A.E., and Sefton, J.M. (2015). Effects of vehicle-ride exposure on cervical pathology: A meta-analysis. Ind Health, 53(3), 197-205. doi: 10.2486/indhealth.2014-0156.

[55] Rios-Tejada, F., Herrera, M., Garcia, J., Garrido, J., and Diaz, C. (1999). Radiological evaluation of the cervical spine of high-performance aircraft pilots of the Spanish Air Force (SPAF). In: R. Burton (Ed.), Cervical Spinal Injury from Repeated Exposures to Sustained Acceleration, pp. 25-27. Neuilly-sur-Seine, France: NATO Research and Technology Organization.

[56] Burns, J.W., Loecker, T.H., Fischer, J.R., Jr., and Bauer, D.H. (1996). Prevalence and significance of spinal disc abnormalities in an asymptomatic acceleration subject panel. Aviat Space Environ Med, 67(9), 849-853.

[57] Hendricksen, I.J., and Holewijn, M. (1999). Degenerative changes in the spine of fighter pilots of the Royal Netherlands Air Force. Aviation Space and Environmental Medicine, 70, 1057-1063.

[58] Petren-Mallmin, M., and Linder, J. (1999). MRI cervical spine findings in asymptomatic fighter pilots. Aviat Space Environ Med, 70(12), 1183-1188.

[59] Petren-Mallmin, M., and Linder, J. (2001). Cervical spine degeneration in fighter pilots and controls: A 5-yr follow-up study. Aviat Space Environ Med, 72(5), 443-446.

[60] Moon, B.J., Choi, K.H., Yun, C., and Ha, Y. (2015). Cross-sectional study of neck pain and cervical sagittal alignment in air force pilots. Aerosp Med Hum Perform, 86(5), 445-451. doi: 10.3357/AMHP.4123.2015.

[61] Loomis, T.A., Hodgdon, J.A., Hervig, L., and Prusacyzk, W.K. (1999). Neck and back pain in E-2C Hawkeye aircrew. San Diego, CA: Naval Health Research Center.

[62] Thomae, M.K., Porteous, J.E., Brock, J.R., Allen, G.D., and Heller, R.F. (1998). Back pain in Australian military helicopter pilots: A preliminary study. Aviat Space Environ Med, 69(5), 468-473.

[63] Äng, B.O., and Harms-Ringdahl, K. (2006). Neck pain and related disability in helicopter pilots: A survey of prevalence and risk factors. Aviation, Space, and Environmental Medicine, 77(7), 713-719.

[64] van den Oord, M.H.A.H., De Loose, V., Meeuwsen, T., Sluiter, J.K., and Frings-Dresen, M.H.W. (2010). Neck pain in military helicopter pilots: Prevalence and associated factors. Military Medicine, 175(1), 55-60.

[65] Sharma, S., and Agarwal, A. (2008). Cervicalgia amongst helicopter pilots using helmet-mounted devices. Indian J Aerosp Med, 52, 1-7.

[66] Hiatt, K., and Rash, C.E. (2011). The reported incidence of man-machine interface issues in Army aviators using the Aviator's Night Vision System (ANVIS) in a combat theatre. Paper presented at the International Society for Optical Engineering, San Diego, CA.

[67] Walters, P.L., Cox, J.M., Clayborne, K., and Hathaway, A.J. (2012). Prevalence of neck and back pain amongst aircrew at the extremes of anthropometric measurements: U.S. Army Aeromedical Research Laboratory Report No 2012-12, Fort Rucker, AL.

[68] Adam, J. (2004). Results of NVG-induced neck strain questionnaire study in CH-146 Griffon aircrew, p. 95. Toronto, Canada: Technical Report DRDC Toronto TR 2004-153 Defence Research and Development Canada, Toronto Research Centre.

[69] Harrison, M.F., Neary, J.P., Albert, W.J., and Croll, J. (2011). Neck pain and muscle function in a population of CH-146 helicopter aircrew. Aviation Space and Environmental Medicine, 82(12), 1125-1130.

[70] Farrell, P.S.E., Chafé, G.S., Karakolis, T., Fusina, G., Hollands, J.G., and Wright-Beatty, H. (2017). Interim scientific advice for six RCAF Griffon helicopter aircrew neck-trouble mitigating solutions. Scientific Letter, DRDC-RDDC-2016-L028, Defence Research and Development Canada, Toronto, Canada.

[71] Harrison, M.F., Neary, J.P., Albert, W.J., and Croll, J.C. (2012). A predictive logistic regression equation for neck pain in helicopter aircrew. Aviation, Space, and Environmental Medicine, 83(6), 604-608.

[72] Grossman, A., Nakdimon, I., Chapnik, L., and Levy, Y. (2012). Back symptoms in aviators flying different aircraft. Aviat Space Environ Med, 83(7), 702-705.

[73] Walters, P.L., Gaydos, S., Kelley, A.M., and Grandizio, C.M. (2013). Spinal pain and occupational disability: A cohort study of British Apache AH Mk 1 pilots: US Army Aeromedical Research Laboratory, Fort Rucker, AL.

[74] Orsello, C.A., Phillips, A.S., and Rice, G.M. (2013). Height and in-flight low back pain association among military helicopter pilots. Aviat Space Environ Med, 84(1), 32-37.

[75] van den Oord, M.H.A.H. (2013). Prevention of flight-related neck pain in military helicopter aircrew: An overview. Paper presented at the Aerospace Medical Association, Chicago, IL.

[76] Fraser, W.D., Crowley, J.S., Shender, B.S., and Lee, V.M. (2015). Multinational survey of neck pain in rotor-wing aircrew, p. 24. TTCP Technical Report DOC-HUM-01-2015: The Technical Cooperation Program.

[77] Nagai, T., Keenan, K.A., Abt, J.P., Sell, T.C., Smalley, B.W., Wirt, M.D., and Lephart, S.M. (2016). A comparison of cervical and trunk musculoskeletal characteristics between female and male army helicopter pilots. International Journal of Aviation, Aeronautics, and Aerospace, 3(3). doi: https://doi.org/10.15394/ijaaa.2016.1136.

[78] Crowley, J.S., Cost, A., Dodson, W.W., and Huber, J. (2018). Study on health of helicopter and tiltrotor pilots: Literature review and epidemiological study. Washington DC: United States Department of Defense.

[79] van den Oord, M.H.A.H., Steinman, Y., Sluiter, J.K., and Frings-Dresen, M.H. (2012). Optimizing aircrew's helmet fit: The effect on neck load. Paper presented at the Aerospace Medical Association, Atlanta, GA.

[80] Aydoq, S.T., Turbedar, E., Demirel, A.H., Tetik, O., Akin, A., and Doral, M.N. (2004). Cervical and lumbar spinal changes diagnosed in four-view radiographs of 732 military pilots. Aviation, Space, and Environmental Medicine, 75, 154-157.

[81] Landau, D.A., Chapnick, L., Yoffe, N., Azaria, B., Goldstein, L., and Atar, E. (2006). Cervical and lumbar MRI findings in aviators as a function of aircraft type. Aviat Space Environ Med, 77(11), 1158-1161.

[82] Byeon, J.H., Kim, J.W., Jeong, H., Sim, Y.J., Kim, D.K., Choi, J. K., … Kim, G.C. (1996). Degenerative changes of spine in helicopter pilots. Annals of Rehabilitation Medicine, 37, 706-712.

[83] Knox, J.B., Deal, J.B., Jr., and Knox, J.A. (2018). Lumbar disc herniation in military helicopter pilots vs. matched controls. Aerosp Med Hum Perform, 89(5), 442-445. doi: 10.3357/AMHP.4935.2018.

[84] Boyd, D., Butler, M., Carr, D., Cohen, M., Devor, M., Dworkin, R., … Woda, A. (1994). Part III pain terms: A current list with definitions and notes on usage. In: H. Merskey and N. Bogduk (Eds.), Classification of Chronic Pain: Descriptions of Chronic Pain Syndromes and Definitions of Pain Terms, 2nd ed., p. 9. Seattle, WA: IASP Press.

[85] Meskey, H., and Boduk, N. (Eds.). (1994). Classification of Chronic Pain: Descriptions of Chronic Pain Syndromes and Definitions of Pain Terms, 2nd ed., Seattle, WA: IASP Press.

[86] Boduk, N., and McGuirk, B. (Eds.). (2006). Classification of Chronic Pain: Descriptions of Chronic Pain Syndromes and Definitions of Pain Terms, 1st ed., Vol. 17: Elsevier.

[87] Guzman, J., Haldeman, S., Carroll, L.J., Carragee, E.J., Hurwitz, E.L., Peloso, P., ... Hogg-Johnson, S. (2008). Clinical practice implications of the Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders: From concepts and findings to recommendations. Spine, 33(4S), S199-S213.

[88] Evans, G. (2014). Identifying and treating the causes of neck pain. Med Clin North Am, 98(3), 645-661. doi: 10.1016/j.mcna.2014.01.015.

[89] Jensen, M.P., and Turk, D.C. (2014). Contributions of psychology to the understanding and treatment of people with chronic pain: Why it matters to ALL psychologists. Am Psychol, 69(2), 105-118. doi: 10.1037/a0035641.

[90] Merskey, H., and Boduk, N. (2004). IASP Task Force for Taxonomy: Pain terminology. Seattle, WA: International Association for the Study of Pain.

[91] Guzman, J., Hurwitz, E.L., Carroll, L.J., Haldeman, S., Côté, P., Carragee, E.J., … Cassidy, J.D. (2009). A new conceptual model of neck pain: Linking onset, course, and care: The Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders. Journal of Manipulative and Physiological Therapeutics, 32(2), S17-S28. doi: http://dx.doi.org/10.1016/j.jmpt.2008.11.007.

[92] Kovacs, F.M., Abraira, V., Zamora, J., Fernandez, C., and Spanish Back Pain Research Network. (2005). The transition from acute to subacute and chronic low back pain: A study based on determinants of quality of life and prediction of chronic disability. Spine (Philadelphia, PA, 1976), 30(15), 1786-1792.

[93] Moore, D.J., Keogh, E., and Eccleston, C. (2012). The interruptive effect of pain on attention. Q J Exp Psychol (Hove), 65(3), 565-586. doi: 10.1080/17470218.2011.626865.

[94] Moore, D.J., Keogh, E., and Eccleston, C. (2013). Headache impairs attentional performance. Pain, 154(9), 1840-1845. doi: 10.1016/j.pain.2013.06.006.

[95] Attridge, N., Noonan, D., Ecclelston, C., and Keogh, E. (2015). The disruptive effects of pain on N-back task performance in a large general population sample. Pain, 156(10), 1885-1891.

[96] Oosterman, J., Derksen, L.C., van Wijck, A., Kessels, R., and Veldhuijzen, D.S. (2012). Executive and attentional functions in chronic pain: Does performance decrease with increasing task load? Pain Res Manag, 159-165.

[97] Druckman, D., and Bjork, R.A. (2015). In a Mind's Eye: Enhancing Human Performance. New York, NY: National Academy Press.

[98] Probert, K., Dyre, B.P., Hollands, J.G., Beaudoin, T., and Maceda, E. (2019). Effect of pain and task load on flying performance. Paper presented at the Symposium on Aviation Psychology, Dayton, OH.

[99] van Leusden, A.J., Prendergast, P.R., and Gray, G.W. (1991). Permanent grounding and flying restrictions in Canadian Forces pilots: A 10-year review. Aviat Space Environ Med, 62(6), 513-516.

[100] Smith, E. (2017). Neck pain in RCAF fighter force pilots. Paper presented at the Aerospace Medical Association, Denver, CO.

[101] Lange, B., Torp-Svendsen, J., and Toft, P. (2011). Neck pain among fighter pilots after the introduction of the JHMCS helmet and NVG in their environment. Aviat Space Environ Med, 82(5), 559-563.

[102] Nagai, T., Abt, J.P., Sell, T.C., Clark, N.C., Smalley, B.W., Wirt, M.D., and Lephart, S.M. (2014). Neck proprioception, strength, flexibility, and posture in pilots with and without neck pain history. Aviat Space Environ Med, 85(5), p 529-535.

Chapter 3 – NECK PAIN ASSESSMENT AND METRICS – USES AND LIMITATIONS

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3.0 SUMMARY

This chapter explores various metrics and methods available for the investigation and analysis of neck pain and injury including a range of modelling tools, questionnaires, rating scales, imaging, and strength assessments. Standardised procedures for Electromyography (EMG) administration and data analysis are also presented to facilitate data sharing and collaboration among NATO countries. A new standardised NATO HFM-252 Aircrew Neck Pain Questionnaire featuring essential core questions to be used in all future questionnaires, (see Annex D), as well as suggestions for optional questions, is recommended for future use. The chapter ends with an additional series of recommendations.

3.1 MODELLING AND SIMULATION METHODOLOGIES TO STUDY SPINAL PAIN AND INJURY

3.1.1 Neck/Spine Models

Modelling is a key tool to explore options to address aircrew neck pain, given the ethical limitations involved with studying human subjects with pain. There are several categories of models, including:

- Conceptual models (models based on logical argumentation);
- First-principle models (models derived from laws of motion, such as conservation of momentum);
- Computational models (fitting mathematical expressions to empirical data) that are used at various stages of the development, design, and assessment of solutions;
- Animal models (use of surrogates to gain insight on human response); and
- Physical models (mechanical surrogates used to measure forces, moments, and kinematic response to dynamic loading) [1].

Each type of model has advantages and disadvantages that must be considered when choosing a model for a specific application. For example, a single joint model may be sufficient for developing design principles and guidelines. A multi-body model may be acceptable for assessing various solutions, such as new counterbalance systems. A finite element model is used to develop an in-depth understanding of stress/strain relationships within and between neck structures due to external cumulative loading.

Models may use experimentally derived constitutive properties of anatomical structures to predict loading and moment conditions that may result in a spectrum of events ranging from sub-injuries, e.g., joint laxity, to frank injury of soft or hard tissue. Unlike predicting bone fracture, the challenge in predicting pain is in understanding its aetiology, i.e., biomechanical, neurogenic, and/or metabolic, the magnitude (primarily defined subjectively), and persistence. Further, predicting the onset of acute pain, for example associated with irritation of a spinal nerve, is quite different from predicting the onset and nature of chronic pain in which time is a variable that includes tissue healing in between loading events.

From an operational perspective, the value of a model is predicated on its ability to be used as a design tool in the development of techniques, procedures, and/or equipment to mitigate the risk of pain. It must be emphasized that risk mitigation does not mean elimination of pain but a reduction in incidence, magnitude, and persistence. From an evolutionary perspective, the body uses its network of pain receptors as a protective cautionary warning to stop performance of an activity.

The following briefly describes examples of the types of models that have been developed to address pain and injury. All have their limitations and should be used with a clear understanding of their underlying assumptions and the boundaries in which they were developed.

3.1.1.1 Conceptual Model

The NATO HFM-252 Aircrew Neck Pain Framework found in Section 1.2 is an example of a conceptual model. Recall that the model is based on a logical argument regarding aircrew: 'who?', 'what?' 'where?' 'when?' 'why?' and 'how?'. Conceptual models are often expressed in terms of prose, but, like first-principle and empirical models, they may also include descriptions of independent and dependent variables and sometimes a relationship between variables. For example, the Neck Pain Framework postulates a relationship between helmet-supported mass properties (independent variables) and aircrew neck pain (dependent variable) where the greater the helmet system mass, imbalance, or inertia, the greater risk of developing neck pain. Logically, solutions that reduce neck-borne mass properties presumably reduce the risk of neck pain. Conceptual models are helpful at understanding a problem and making inferences; however, they do not go any further than describing variables and potential relationships between them.

3.1.1.2 Computational Ligamentous Models

The value of computational models is their ability to explore dynamic loading conditions and predict injury outcome in a cost-efficient manner. These models are also used to identify unknowns and plan experiments to fill these gaps. Finally, once validated, models can be used to create design criteria to mitigate injury risk. Historically, risk criteria have been developed based on automotive crash data conducted with instrumented anthropometric manikins or on studies using aged cadaveric specimens whose response has limited applicability to the military population. The US Office of Naval Research sponsored a multidisciplinary effort led by the US Naval Air Systems Command to quantitatively determine spinal injury risk. This effort included conducting studies specifically designed to address the gaps in the clinical and aerospace literature and develop tools to predict injurious exposure thresholds. To build this model, geometric, materials properties and constitutive equations describing spinal hard and soft tissues sub-failure and failure responses were determined. Biomechanical data were obtained during quasi-static and dynamic conditions using Post-Mortem Human Specimens (PMHS) whose age and size were appropriate to US naval aviators. This required the development of new test fixtures and measurement techniques. These data were obtained by the Medical College of Wisconsin, Duke University, and the University of Virginia Center for Applied Biomechanics. Geometric and mechanical tissue properties were determined by:

- Quantitative Computed Tomography (QCT; providing geometric and Bone Mineral Density (BMD) data);
- Cryomicrotomy (used to determine soft tissue geometry and attachment points by sectioning a frozen specimen at approximately 750 to 1250 micron intervals in the sagittal plane); and
- Measuring the sub-failure material properties of the cervical column (C2-T1), motion segments (two vertebrae with the intervertebral disc), and failure characteristics of C6 and C7.

Quasi-static and dynamic material properties were determined in the following load conditions: flexion, extension, lateral bending, axial rotation, axial tension, axial compression, load relaxation, and combined loading.

The QCT database contains a comprehensive set of geometric and BMD information ever collected of normal healthy males and females ranging from 18 – 40 years, with a minimum height of 5’0’’ (152.4 cm) [2], [3]. Female volunteers range from 90 to 165 lb (40.8 to 74.8 kg) and males from 120 to 240 lb (54.4 to 108.9 kg). Ninety male and ninety female datasets were collected. Three-mm helical scans from the base of C1 through T1 were obtained and reconstructed at 1.5-mm intervals. For the lumbar spine, 10-mm sequence axial scans of the L2, L3 and L4 vertebra were obtained at mid-depth.

To determine soft tissue properties of cervical spinal ligaments and intervertebral discs, an Instron device was used for the former and a custom designed Impactor was developed for the latter. The Instron force test machine is used for uniaxial tests in an orientation that is representative of physiological conditions. It is capable of a velocity of approximately 1.5 m/s and a maximum force of approximately 4000 N. An important design parameter when manufacturing the test fixture was to maintain a physiological environment, so the ligaments were mounted and tested as they are *in vivo*. As such, the entire fixture was an enclosed environmental chamber, which was used to provide a controlled temperature of 37.2°C ± 0.6°C and a controlled humidity > 90 [4]. The Impactor applies a local deformation with a hemispherical impactor to the disc. To control the impact, the fixture features an accelerometer, load cell, and X-Y positioning device. With this fixture sub-failure and failure thresholds were determined.

Whole-neck kinematic responses can be determined using a mini-sled in which the head and neck are exposed to a range of loading conditions in pure moment and combined vectors simulating crash, ejection, and sub-injurious conditions [5]. Determining the geometry of spinal foramina using upright MRI has been shown to be able to delineate pertinent differences between patients diagnosed with radiculopathy and asymptomatic volunteers. These findings could provide an indication of potential pain when loading profiles are imposed on a spinal model indicate conditions for reduced cross-sectional foraminal area [6].

A viscoelastic model was developed to characterise the force response of cervical spinal ligaments and intervertebral discs using the response of the lower step strain to predict the response of the oscillatory strain of varying frequencies and a step strain of a different magnitude. With this approach, it is possible to identify failure characteristics and develop injury risk functions.

The experimental data collected on the spinal structural and material properties was used by Southwest Research Institute to create an anatomically based parameterized probabilistic finite element statistical shape density model and define required probability distributions [7]. NESSUS and LS-DYNA computing tools were used to simulate uncertainty and variability including loads (e.g., impact acceleration during high-speed ejection), material properties (e.g., vertebrae elasticity constant, Poisson’s ratio), and geometries, and to compute the probability of exceeding certain injury tolerance levels. The analysis relates the spinal response probability distributions and the input probabilistic distributions. A parameterized approach allows for rapid reconfiguration of the model to account for differences in anthropometry and sex. As the model was developed, an integrated model verification/validation procedure was successfully employed to test model predictions against both quasi-static and dynamic test results. This procedure reduced the model development time by ensuring internal consistency and the validity of the mathematical processes and assumptions.

3.1.1.3 Soft and Hard Tissue Modelling Software

Biomechanical modelling software, such as Visual 3D and Software for Interactive Musculoskeletal Modelling (SIMM), are used to estimate neck tissue loading due to neck supported mass and dynamic neck movements. Visual 3D focuses on the compression and shear forces at neck joints (hard tissues), while SIMM resolves these forces along various muscles (soft tissue) in their muscle model.

Visual 3D accepts motion capture data and generates a neck joint angular displacement and acceleration, and then uses these values along with neck-supported mass properties to estimate compression and shear forces, as well as torque at the neck joint.

SIMM is a commercial software application designed to enable the user to create and analyse graphics-based models of the musculoskeletal system. The original funding for development of SIMM came from the Rehabilitation Research and Development Center, Veteran’s Affairs Medical Center, Palo Alto, and the software was further developed and marketed by Musculographics, Inc., now part of Motion Analysis Corporation (www.musculographics.com). The software was originally developed to assist in the planning of tendon transfer surgery for the treatment of patients with spasticity, cerebral palsy, and other similar gait deficits. Within SIMM, a musculoskeletal model is constructed that comprises of a set of bones (defined by a bone file) that are connected by joints (defined by a joint file). Muscle-tendon actuators and ligaments (defined by a muscle file) span these joints. When in motion, muscles and ligaments develop force, thus they generate moments about the joints. The basis of the muscle force calculations is the Hill equation [8].

SIMM allows the user to develop, analyse, and test a musculoskeletal model by calculating the moment arms and lengths of the muscles and ligaments. SIMM accounts for the change in length of the muscle and how this influences all the moments it generates. Given certain muscle activation characteristics (which can be estimated using real EMG data), the forces and joint moments (muscle force multiplied by moment arm) generated by each muscle can be estimated for any position of the body. The model is manipulated using either a graphical interface or motion capture data gathered from a human subject. This allows the effects of changing musculoskeletal geometry and other model parameters on muscle forces and joint moments to be explored.

SIMM has a full body musculoskeletal model of an average, adult male that was developed jointly by biomechanics research labs at several universities. This model contains 86 degrees of freedom, 117 joints, and 344 muscle-tendon actuators. The model is symmetric about the sagittal plane. The joints have anatomically accurate kinematics. The muscle-tendon actuators include the force-generating properties so that SIMM can calculate the length, moment arm, force, and joint moment for any muscle in any body position. The skeletal geometry and muscular parameters of the model can be modified to be more representative of the population of interest.

The UK are using SIMM to determine the response of the neck muscles to different helmet mass properties and levels of Gz acceleration, with the ultimate aim of identifying helmet mass properties that reduce the incidence of neck pain in aircrew. The SIMM musculoskeletal model was used to model the force response of 26 muscles located on the left side of the neck during head roll, pitch, and yaw. The decision was made to only run one side to reduce simulation time. Each simulation was performed with different head mass properties: a mass increase up to 5 kg or a head CoM displacement up to ± 5 cm forward-backward, up-down, or left-right. Multiple head angles were investigated in each of roll, pitch, and yaw angles in 10-degree steps up to what would have been the maximum range of motion. The effect of increasing acceleration up to +9 Gz was also investigated. The model output was evaluated to determine which muscles were sensitive to changes in mass properties and what level of force they generated. Subsequently, using a 'helmet' segment modification to the model, the utility of SIMM for comparing UK Ministry of Defence (MOD) helmets was investigated. The work found that neck extensor muscles are the most sensitive to changes in head mass, CoM, and Gz under static conditions and pitch movements resulted in the highest muscle force production. Of all the factors investigated, Gz had the greatest effect on the force response of the muscle. The modelling conducted using the 'helmet' segment revealed that the heavier more balanced helmet elicited less muscle force than the lighter less balanced helmet during head pitch [9]. This initial research only looked at static movements, mass properties, and environmental stressors in isolation.

Subsequently, comparison of SIMM derived muscle activations against empirically measured muscle activations in human volunteers, during simple and complex dynamic head movements while at elevated +Gz levels and with and without the use of helmets, has been conducted [10]. This study found that applying generic scaling factors to the SIMM model provided a more accurate output in terms of muscle activation. SIMM was also capable of producing neck muscle activations representative of those recorded during simple dynamic head movements (pitch). In contrast, when more complex head movements representative of aircrew tasks were conducted, there was considerable variability in the SIMM output related to individual muscles compared to empirically derived muscle activations. However, when larger functional muscle groups were assessed as a whole (e.g., all neck extensors), the variability was reduced. Further investigation of the use of SIMM has been proposed where modifications are made to the algorithms and/or the muscle excitation patterns defined by SIMM to improve the output related to muscle activations.

The RAAF has recently sponsored research with the University of Canberra to better understand the forces. In 2017 – 2018, the RAAF sponsored research with the University of Canberra to better understand the forces experienced by their fast jet aircrew, particularly when flying BFM/ACM sorties where high levels of Gz are experienced and complex dynamic head movements are required. The project has used an OpenSim model of the cervical spine developed at the University of Bath [11]. (OpenSim is a freely available software package (written in C++ with a Java graphical user interface) that can be used to build, exchange, and analyse computer models of the musculoskeletal system and dynamic simulations of movement. OpenSim enhances SIMM and the SIMM Dynamics Pipeline capabilities by providing additional simulation and control capabilities. Since it is open source, OpenSim's object-oriented, modular design allows users to add functionality and share with other OpenSim users.) The OpenSim model took data inputs from a Vicon motion capture system (whereby qualified aircrew completed a number of different head dynamic movements wearing JHMCS and HGU-55/P helmets while seated in an F/A-18 ejection seat), and from F/A-18 JHMCS helmet position and Gz meter data (downloaded from multiple ACM/BFM sorties and verified against HUD-mounted GoPro video footage).

The outcomes of the project will allow the estimation of joint moments within the cervical spine of fast jet aircrew during a selection of 'typical' ACM/BFM sorties, and also for a number of specific head movements under a variety of different +Gz levels (up to and including +9 Gz). A workload algorithm and head motion classification system will be developed. The relevance of these findings will allow for better targeted conditioning programmes for the cervical spine of fast jet aircrew. Additionally, it will allow comparison of the forces experienced in such conditions with helmets of varying weights and centre of mass profiles, thereby informing the relevance of future helmet configurations in the early stages of development. Future projects by University of Canberra may build upon this work by using prospective data capture and modelling combined with prospective injury data to better understand the risks associated with the high Gz and dynamic head movements required when flying ACM/BFM sorties.

3.1.1.4 Physical Model

A physical model can be used to determine loads and moments. This type of model provides empirical data that can be used to define input stress corridors for computational and musculoskeletal models. For example, the effects of added weight and change in centre-of-gravity were determined during a centrifuge study using an instrumented anthropomorphic test device at the Brooks Air Force Base (AFB), Texas centrifuge [12]. Data included centrifuge Gz, head acceleration (three axes), and head and C7-T1 pitch moment, compressive and shear forces. Helicopter (0.5 G/s at +1.75 and +4 Gz) and tactical aircraft (2 G/s and 6 G/s from +4 to +12 Gz) representative accelerations were simulated (5 s plateau at each level). Effects of added weights (up to overall 2.7 kg) were measured in the forward pitch and lateral planes and tested using Analysis of Variance. Seven real helmet systems were also tested. Head Gx and Gy increased with increasing +Gz load, head weight, as CG shifted in the forward pitch plane, and onset rate. Head Gz was greatest when weight was distributed laterally. The resultant head and neck force and moment increased with increasing weight, pitch angle, and +Gz load. Neck forces and moments were significantly larger than those measured in the head.

3.1.1.5 Digital Human Modelling in Military Aviation for Visualization and Form/Fit Analyses

Digital Human Modelling (DHM) in one of its earliest forms was used by the Boeing Company to assess reach in the late 1960s. DHM tools used to simulate and assess human system interfaces have advanced since then, with the development of new products along with regular capability updates. The use of DHM in the automotive industry is widespread and well known, but other commercial and military organizations also utilise these tools with a different set of applications and challenges.

The software packages most commonly used at this time are Delmia (Dassault Systèmes), Jack (Siemens), Santos® (SantosHuman Inc.), and RAMSIS (Intrinsys). Each of these products has different capabilities, strengths, and weaknesses. There is no one best tool. Some DHM efforts are also performed using the limited functionality available in Computer Aided Design packages, but this is not generally acceptable for military applications. There are also some older DHM tools that were more common in the late 1990s and 2000s, but are not seen often, if at all, now for military aviation applications. A few examples include Combiman, Boeing McDonnell Douglas Human Modeling System, and Sammie.

Current military aviation applications of the DHM focuses on aircrew accommodation and ergonomics, crew endurance, Unmanned Aircraft System workstation layout, and aircraft maintainer accommodation (aircraft system maintainability and accessibility, flight deck operations, lifting limits, required strength/forces, etc.). To address neck and back injury/pain in the military aviation community, several military organizations are currently researching technologies such as Inertial Measurement Units and fibre optics to record pilot postures, which can then be used in DHM to identify the largest contributors to the issues and potential mitigations. The DHM packages also have a variety of other features and capabilities (thermal burden, vibration, injury, etc.) that may be of use in military aviation; however, there are still challenges to address with regard to the primary uses of the software.

The large commercial DHM packages are commonly used in automotive design applications. This is not the case for military aviation, most especially with respect to aircrew accommodation. There are multiple challenges in using DHM for aircrew accommodation evaluation. The avatar or manikin must be anthropometrically accurate to represent the boundaries of the target population, or for univariate analysis is representative of the appropriate percentile for the specific measurement of interest. This means that current databases must be integrated into the software, boundary cases determined, and the software have the capability of allowing accurate dimensioning of all relevant anthropometry. Military pilots wear a significant amount of pilot flight equipment. This adds bulk and affects the position the pilot sits in, the ability to see and reach, and available clearance. There is also the seat restraint system to consider. Military pilots have to fly with a locked harness at times, which limits reach to controls, but accurate restraint systems cannot be implemented in current DHM packages. Cushion compression and flesh compression also have an impact on how a pilot sits in the cockpit. A variety of Validation and Verification (V&V) efforts have been performed by the USAF and United States Navy (USN), but to date, none of the DHM packages have been through comprehensive V&V, and at this time DHM should be used for aircrew accommodation purposes only with full acknowledgement of the limitations and with the utmost caution. A few other limitations of the DHM software should also be considered. The software does not usually represent the aircraft or shipboard dynamic environment. And, the software may not do a good job of identifying endurance issues. The software may indicate a pilot is accommodated for a moment in time, but not tell us that at the three-hour mark of a flight, the pilot has developed pain from a seat pressure point. Therefore, caution must be taken when attempting to draw endurance conclusions from DHM analysis.

3.1.1.6 Task and Physical Demand Models

Chronic neck pain is associated with cumulated neck load exposure from task performance (often repetitive), dynamics missions, and a career of flying. A new technique has been developed to systematically collect neck joint angles for each task and postural sequence over the course of a mission. This technique is derived from two established analyses of human work:

1) Task analyses; and
2) Physical demands analyses [1].

Behavioural task analysis or Mission, Function, Task Analysis (MFTA) provides a methodology to systematically decompose a mission into a hierarchy of functions [13], [14]. Functions are allocated to either machines or humans. Once allocated to humans, functions are renamed as tasks. These human tasks can be further decomposed into subtasks, and so on, down to an abstraction level where useful analyses, such as neck load estimates, can be conducted. Once the task hierarchy has been mapped out, they may be reconstituted into a complete mission that now includes cumulative neck loads. An example of this modelling technique is given in Chapter 6.

3.1.2 Model Limitations

Use of any of these models must be applied only for the conditions in which the model was validated. While developing a digital representation of physical and anatomic systems is relatively straightforward, the model is only good for the underlying assumptions used when it was created. To determine its relevance to provide design guidelines for military purposes, users must know if the following apply to the question being asked (e.g., will this reduce neck pain incidence?):

- Input data;
- The conditions the data were obtained under (temperature, humidity, loading magnitude, direction, onset rate, profile, etc.);
- Applicability to the population of interest (sex, age);
- Relevant loading vectors, postures;
- Appropriate use of animal surrogate data (scaling);
- Number of specimens used;
- The limitation of PMHS use for dynamic testing in which muscles are not active; and
- The availability of military-relevant validation data.

The inherently subjective and complex nature of pain is difficult to accurately model for predicting general population responses. A comprehensive model would need to account for biomechanical, metabolic, soft and hard tissue origins. It is possible to infer the presence of acute pain if model predictions indicate nerve impingement due to narrowing of spinal foramina, as mentioned in Section 3.1.1.2 in a study comparing radiculopathy to pain-free volunteers [6]. However, this has not been shown to provide insights on modelling chronic spinal pain. A model that takes into account lumbar spine anatomy, muscle structure, fatigue, and metabolic species production, e.g., lactate, H+, is under development that may predict the onset of chronic low back pain. A preliminary summary of this was reported by Whitley et al. [15].

3.1.3 Model Verification and Validation

Verification is the process of determining that a model implementation accurately represents the developer's conceptual description of the model and its solution. Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model [16]. Model V&V are processes that provide evidence that a model is accurate for a specific scenario; however, it cannot prove that a model is correct and accurate for all possible scenarios. Therefore, model V&V is a process that is never fully completed, but rather concluded when acceptable accuracy is achieved.

Mitigating the risk of neck pain and injury during military operations requires a fundamental understanding of the injury mechanisms associated with the transmittance of loads through the human body and the ensuing kinematic response to these loads. This understanding can then be used to develop operational procedures, equipment, clothing, and procedures to minimise the risk of injury. However, the variability of loading, cockpit geometry, behaviours, and anatomical differences associated with aviator size and sex, require the use of numerical modelling and simulation to predict the uncertain behaviour and response of the human body to extreme loads.

Validation criteria must be applicable to injury of interest and be medically relevant, i.e., type, magnitude, and location of injury predictions are consistent with recognised medical practice. Model output should be actionable, i.e., to develop injury criteria for design recommendations and provide an indication of the relevance of the model prediction. For example, if a model predicts a 20% risk of mid-cervical spine joint laxity, the model should describe how that translates into an operational relevant outcome; e.g., will this result in grounding the pilot.

One approach, as described by Thacker, Francis and Nicholella [17], stressed that the credibility in these predictions is established through the application of formal model V&V practices and procedures. A critical aspect to V&V applied to highly complex models where uncertainties are large and testing is especially difficult is the use of a validation hierarchy where the full system model is subdivided into its constituent subassemblies and components. Model V&V is then applied to each sub model in the hierarchy such that the error and confidence in the full system prediction can be quantified.

3.2 SUBJECTIVE MEASURES

Subjective or qualitative assessments rely on a person's feelings, which in turn are based upon their experience and judgement. Such metrics are often based upon interviews of the individual or evaluations of the subjects' observable behaviour. Alongside these subjective measures, ratings or questionnaires are used where there is a systematic attempt to establish a quantifiable measurement scale that has clearly defined endpoints. There are various types of tools developed to capture this information, ranging from simple ratings along a continuum, which are obtained by the subject choosing a point or statement that represents their current state, to somewhat more compound ratings based upon the number, type, and/or frequency of statements chosen out of a list that express the subjects' current state/feelings.

In occupational, clinical, and experimental settings, ratings or questionnaires are used to provide descriptors of intensity or ratings of what individuals are experiencing (e.g., levels of comfort/discomfort, pain, fatigue, or workload). Subjective measures are often criticized as they are influenced by interpretation and opinion, as compared with more quantifiable objective measures. However, in occupational and experimental settings, ratings or questionnaires can be a valuable source of information with regards to changes in perception relative to one's previous responses (e.g., increases in pain perception or levels of fatigue may have important safety and operational implications) and/or when collected from large population groups.

For clinical use, Aviation Medicine Providers should use validated diagnostic or therapeutic metrics in order to understand the experienced level of pain, fatigue, comfort/discomfort, psychosocial factors, general health, and physical and cognitive exertion. For research purposes, it is important to select acknowledged metric tools that safeguard the requirements of reproducible methodology and consistency. It is also important to recognise that the neck is just one part of a larger system and the spine and rest of the body influence perceived issues. In order to treat a neck problem, one has to consider the possibility of pathologic findings on other parts of the body, e.g., strain on lower back.

Outlined below are a summary of rating scales or questionnaires currently used during either experimental or clinical applications for parameters related to neck and back pain.

3.2.1 Pain

Acute and chronic pain questionnaires are used to identify prior pain experiences, evaluate the current status of pain, and document any changes in pain as a result of a worsening condition or treatment improvements. In aviation, the assessment of treatment effectiveness and/or interventions to reduce symptoms related to neck strain is particularly important. Questionnaires or rating scales that are currently used to examine an individual's pain history and/or current pain ratings are outlined below.

3.2.1.1 Pain History

Two types of Nordic questionnaires are used to examine general and specific pain issues [18], [19]. The general questionnaire inquires whether individuals have, or have had, issues within nine anatomical regions during the past twelve months and whether the pain is disabling and/or ongoing. The specific questionnaire focuses on the lower back and neck/shoulders with questions related to duration of symptoms over the individuals' entire life, the past twelve months, and the previous seven days. It also elicits information regarding the severity of symptoms and their effect on activities at work and during leisure time, as well as information on the total duration of symptoms and sick leave taken during the past twelve months.

The Bournemouth Questionnaire subset on the neck consists of seven questions regarding neck pain over the past week [20]. Patients use a zero to ten rating scale and provide information regarding interference with recreational, social, and family activities, interference with daily activities, anxious feelings, depressed feelings/thoughts, and perceived control over their pain.

The Orebro Musculoskeletal Pain Questionnaire (OMPQ) is used to predict the outcome of acute and sub-acute back pain with regards to predicting long-term disability and failure to return to work due to personal and environmental factors [21], [22]. The questionnaire consists of 21 scored questions, with ratings between zero (e.g., not at all, no pain, never) and ten (e.g., extremely, pain as bad as it could be, always) with a cut-off of 105 as a score to identify yellow flags and/or concerns in acute low back pain patients. In a population with chronic non-specific low back pain, the OMPQ cut-off score was 89 [23].

The Short Form 36 Bodily Pain Scale (SF-36 BPS) is one of the eight subscales of the Medical Outcomes Study SF-36 BPS questionnaire [24], [25]. The questionnaire quickly (< 5 minutes) gathers information regarding the frequency of bodily pain or discomfort using ten scale levels from Low (very severe and extremely limiting pain) to High (no pain or limitations due to pain) within the past four weeks. The SF-36 BPS is available in both standard (4 week) and acute (1 week) versions and can be completed as self-administration, computerized administration, or interview administered.

3.2.1.2 Visual, Numeric, and Verbal Pain Ratings

The Visual Analogue Scale (VAS) (Figure 3-1) is psychometric response scale for rating pain, often 10 cm in length anchored by two extremes: zero (no pain) to ten or one hundred (pain as bad as it could be, or worst imaginable pain) [26], [27], [28], [29]. Respondents specify their level of agreement with a statement by indicating a position along a continuous line regarding pain intensity within the past 24 hours. Administration is quick (< 1 minute) and measures subjective characteristics or attitudes that cannot be directly measured. Sensitivity and reproducibility of the results are similar to that of other linear scales, such as the Likert or Borg scales [30], though the VAS is more exact given the measurement along the continuum.

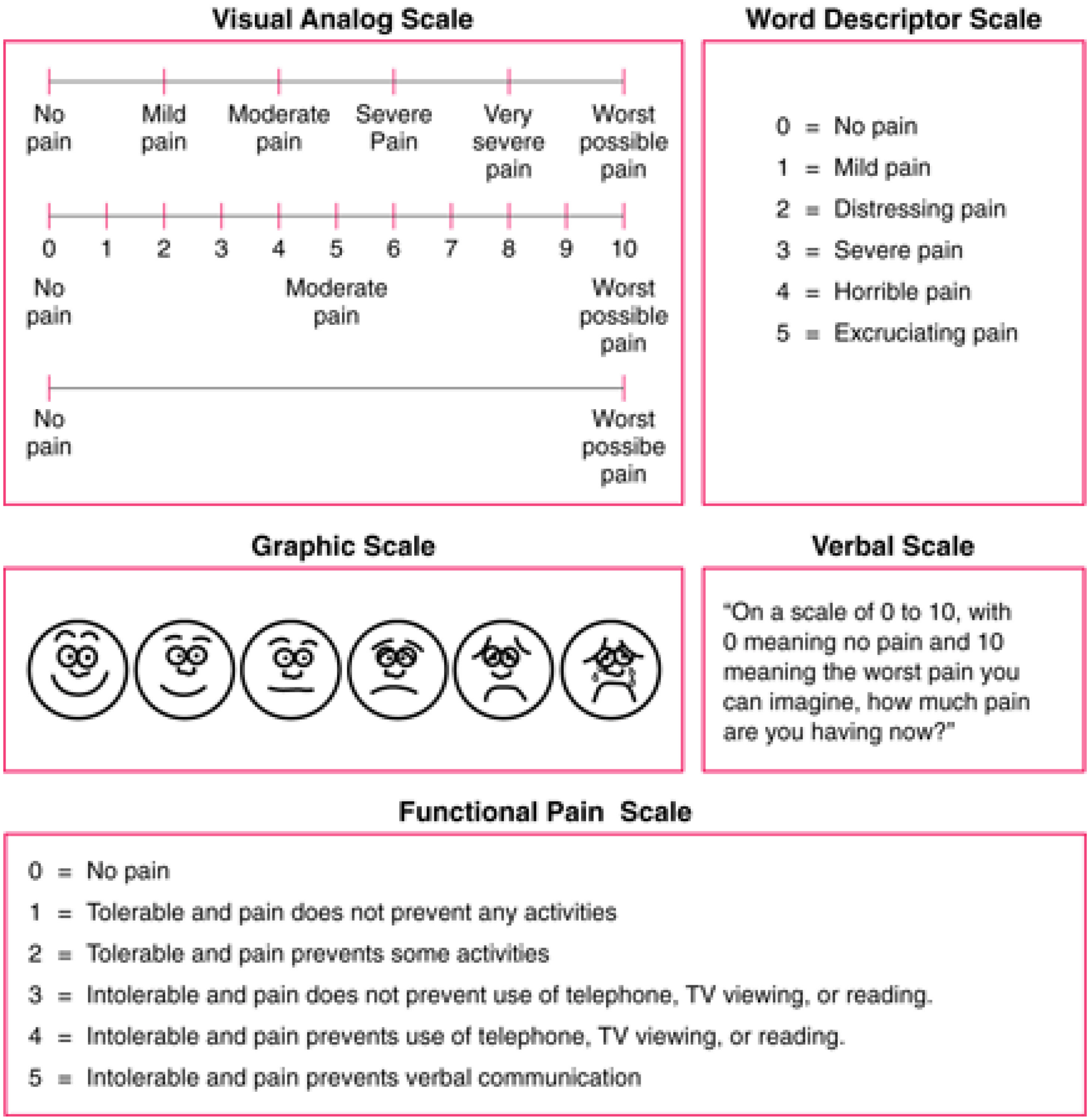

Figure 3-1: Pain Scales [26], [27], [28], [29], [30], [31], [33], [34], [36].

An accurate pain assessment tool is an essential part of the clinical history taking process, in order for a clinician to be able to manage pain effectively. This is especially important in circumstances where multiple healthcare providers may be involved in the assessment and management of a patient. Each clinician must attempt to quantify the severity of the pain, using a valid and reliable tool, in order to standardize communication of pain experienced between healthcare providers and the patient. The Numeric Rating Pain Scale (NRPS) is the most commonly taught tool to elicit pain severity in medical education [31], due to its favourable Minimal Detectable Change and test-retest reliability [32]. The NRPS is an eleven-point pain scale from zero (no pain) to ten (pain as bad as you can imagine or worst pain imaginable), which is sensitive to chronic low back pain [26], [33], [34] (Figure 3-1). This rating can be obtained quickly (< 1 minute) in writing or verbally, and has good sensitivity while producing data that can be statistically analysed [35]. The visual FACES rating scale is also used with and without a numeric rating scale [36] (Figure 3-1).

3.2.1.3 Pain Questionnaires

The McGill Pain Questionnaire consists of four subscales that obtain a measure of sensory, affective, evaluative, and miscellaneous aspects of pain, as well as pain intensity in adults with chronic pain. These components comprise the Pain Rating Index, which contains 78 pain descriptors categorized into twenty subclasses, and uses a five-point pain intensity scale; the Melzack Pain Intensity Scale [37]. This questionnaire is interviewer-administered and can take up to twenty minutes.

The Multidimensional Pain Inventory – Part I consists of three parts and twelve scales which examine the impact of pain on daily living (including perceived pain intensity), the patients' perceptions of the responses of significant others / family to their pain communications, and the extent that patients are able to participate in common daily activities [38].

The Neck Disability Index (NDI; http://www.physio-pedia.com/Neck_Disability_Index) is a modification of the Oswestry Low Back Pain Disability index (http://www.physio-pedia.com/Oswestry_Disability_Index), which is used to assess self-rated disability, in addition to current pain levels, on ten items, each with a score up to five (Total score out of 50: 0 – 4 no disability, 5 – 14 mild, 15 – 24 moderate, 25 – 34 severe, and 35+ complete disability) [39], [40], [41]. It is a patient-completed, condition-specific functional status questionnaire with ten items including pain, personal care, lifting, reading, headaches, concentration, work, driving, sleeping, and recreation. The NDI has sufficient support and usefulness to retain its status as the most commonly used self-report measure for neck pain [42]. The NDI can be used to evaluate the patient's status and to evaluate their evolution during therapy. The NDI appears to demonstrate adequate responsiveness in patients with neck pain and concomitant upper extremity referred symptoms. However, NDI does not include any occupation-related neck pain questions, and under-reports the severity and disability of flying-related neck pain [43].

The Neck Disability Index-5 is a shorter version that contains only five of the originally described items that is often used due to the time burden of the full NDI [44].

3.2.2 Fatigue

Physical and mental fatigue rating scales and questionnaires are used clinically and experimentally as measurement tools for assessing workload issues, recovery needs, cognitive difficulties, and overall fatigue changes that result from a treatment and/or intervention. Questionnaires currently used within clinical and experimental assessments of fatigue include the following:

- The Checklist Individual Strength-20 consists of twenty statements that provide a measure of total fatigue [45], [46]. This is further broken down to give scores of four elements of fatigue, including subjective experience of fatigue (8), reduced concentration (5), reduced motivation (4), and reduced physical activity level (3). Although the questionnaire was originally designed for Chronic Fatigue Syndrome patients, it has been validated as being appropriate for healthy populations as an indicator of fatigue to assess whether or not to grant sick leave or work disability.
- The Chalder Fatigue Questionnaire assesses the severity of fatigue using a five-point rating scale in eleven items [47]. The quick (2 – 5 minutes) paper/pencil questionnaire incorporates physical fatigue

(e.g., lack of energy, feeling weak, less muscle strength, the need to rest) and mental fatigue (e.g., concentration, memory) while showing sensitivity to treatment changes.

- The Fatigue Assessment Scale (FAS) is a ten-item questionnaire, which uses a five-point rating scale to assess physical and mental fatigue [48]. FAS can also be used to derive a total fatigue score, with the understanding that it does not include emotional stability and/or depression.
- The Short Form-36 Vitality subscale of the Short Form Health Survey measures total vitality through ratings regarding energy level and fatigue [25]. This subscale survey can be quickly (< 1 minute) self-administered, or completed on computer, or by an interviewer. Higher scores indicate greater energy and lower fatigue.
- The Emotional Exhaustion subscale of the Maslach Burnout Inventory obtains information to describe feelings of being emotionally overextended and exhausted by an individual's work [49].
- The Energy and Fatigue subscale from the World Health Organization Quality of Life assessment instrument uses a five-point Likert scale to assess the level of energy versus fatigue [50].
- A modified Borg scale is also used as a quick subjective measure of fatigue using a zero (No Fatigue) to ten (Maximum Fatigue) scale [51].

3.2.3 Comfort and Discomfort

Subjective measures of comfort and discomfort can pertain to one's perception at different locations of the body or as a whole-body response. Comfort and discomfort ratings may be influenced by factors such as posture, pressure points, thermal environment, etc., and are important indicators given they can influence an individual's state, and thus safety and operations. The following are some of the currently used questionnaires and ratings of comfort and discomfort:

- The Seating Comfort Questionnaire assesses the level of discomfort on a scale from zero (No Discomfort) to eleven (Maximal Discomfort [52]. Several locations on the body from head to toe can be assessed using the same scale to obtain regional discomfort perceptions.
- The Automotive Seating Discomfort Questionnaire consists of twenty questions/statements pertaining to cushion characteristics (e.g., length, firmness, backrest, contour, etc.) in which individual's respond on a sliding scale from No Discomfort/Objections to Extreme Discomfort/Objections [53]. This questionnaire is sensitive to changes within the physical components of the seat and is not influenced by sex.
- The Postural Discomfort scale assesses overall discomfort at fifteen locations on the body using a seven-point scale from 'Extremely uncomfortable' to 'Extremely comfortable' [54]. The fifteen locations are the legs, thighs, buttocks, lower back, mid back, upper back, lower arms, upper arms, shoulders, and neck, with a left and right response for the extremities and shoulders.
- The Localised Postural Discomfort scale assesses regional musculoskeletal discomfort at thirteen locations using a zero (no discomfort at all) to ten (almost maximum / extreme discomfort) numbered scale [55]. The thirteen locations are the legs, buttocks, lower back, upper back, shoulders, arms, and neck. This scale focuses on discomfort resulting from tension, fatigue, soreness, heat, tremor, pressure in muscles, or subjective level of effort.
- The End-of-Day Comfort Questionnaire is used within occupational settings for aircrew to assess pain/discomfort, hot spots, and numbness [52]. Individuals respond to the three points of interest on a one (i.e., no discomfort / hot spots / numbness) to ten (i.e., unbearable discomfort, severe hot spots, complete numbness) point sliding scale.

- The Tampa Scale for Kinesiophobia (TSK) is used as a subjective rating of kinesiophobia or fear of movement [56]. It consists of seventeen questions on a sliding scale from one (strongly disagree) to four (strongly agree). The TSK was originally designed to measure fear of movement related to chronic low back pain; however, additional studies have also validated it for pain related to different areas of the body, including the cervical spine.

3.2.4 Psychosocial Factors and General Health

Psychosocial factors, such as anxiety, depression, and stress, are important factors to consider when interacting with individuals experiencing neck pain given that they influence individuals' behaviours and the perception of neck pain. Within such communities as the military, questionnaires addressing psychosocial factors are often incorporated upon the initiation of treatment for neck / lower back pain and upon completion to assist in assessing the progression of treatment. In experimental settings, such questionnaires are used to gather information about a participant that may influence the other data being collected and/or assess any changes in the state of a participant as a result of the experimental protocol. Commonly used psychosocial scales and/or questionnaires include the following:

- The Health Anxiety and Depression Scale is used to determine levels of anxiety and depression while avoiding the incorporation of information regarding symptoms, such as fatigue and insomnia, which are common to numerous medical conditions and states of health [57]. This questionnaire includes fourteen points, of which seven are geared towards anxiety and seven for depression, where a rating from four options is given.
- The Distress Risk Assessment Method (DRAM) is a psychological assessment method for individuals with low back pain that is intended to be used as an initial screening and/or to alert clinicians/experimenters that additional assessment may be required [58]. The DRAM classifies individuals as normal, at risk, distressed depressive, or distressed somatic based on the responses from two short questionnaires.
- The Patient Health Questionnaire-15 consists of fifteen somatic symptoms where individuals respond to each symptom on a scale from zero (not bothered at all) to two (bothered a lot) [59]. This questionnaire is useful in clinical practice and research for monitoring the changes in severity of somatic symptoms.
- The Short Form Health Survey (SF-36) is designed for clinical practice and research, health policy evaluations, and general population surveys to be used for self-administration or by a trained interviewer [25]. This survey includes one multi-item scale which assesses eight health concerns, as outlined by Ware and Sherbourne (1992) as follows:
    1) Limitations in physical activities because of health problems;
    2) Limitations in social activities because of physical or emotional problems;
    3) Limitations in usual role activities because of physical health problems;
    4) Bodily pain;
    5) General mental health (psychological distress and well-being);
    6) Limitations in usual role activities because of emotional problems;
    7) Vitality (energy and fatigue); and
    8) General health.

- The Dundee Stress State Questionnaire (DSSQ) measures affective, motivational, and cognitive state changes related to arousal, mood, and fatigue. The DSSQ contains ninety questions broken down into four sections (mood state, motivation, thinking style, and thinking content) in which an individual responds to four-to-five-point rating scales. Pre- and post-versions of the DSSQ are used regularly to detect changes in the individual's state due to task demands, and are ideal for immediate stress states given that it is sensitive to environmental stress [60].
- The Pain Catastrophizing Scale is a thirteen item questionnaire which elicits information about past painful experiences giving a total pain score and three subscale scores assessing rumination, magnification, and helplessness [61], [62]. Individuals are asked to indicate the degree, on a five-point scale from zero (not at all) to four (all the time), that they experienced each of the thirteen thoughts or feelings when experiencing pain.

In addition to the above four psychosocial questionnaires, the Obstacle to Return to Work Questionnaire (ORTWQ) [63] and Baecke Questionnaire [64] are often used as part of an individuals' assessment of general health. The ORTWQ consists of 87 items broken down into the three components of:

1) Pain intensity and depression (9);
2) Obstacles to return-to-work at the workplace and in the family (72); and
3) Motivation for return-to-work (6).

Marhold et al. [63] further broke down the 87 items into nine subscales, including depression, pain intensity, physical workload and harmfulness, social support at work, perceived prognosis of work return, difficulties at work return, worry due to sick leave, work satisfaction, and family situation and support. The ORTWQ was found to be a good predictor of sick leave, which correctly classified 79% of all patients in the first five of the nine categories listed in the previous sentence. Secondly, the Baecke Questionnaire is also used to assess an individual's level of habitual physical activity, including physical activity at work, sport during leisure time, and physical activity during leisure time excluding sport [64].

3.2.5 Workload and Physical Exertion

The NASA Task Load Index (TLX) is one of the most commonly used subjective workload assessment tools, which obtains an overall workload score based on the weighted average ratings from six subscales [65]. The six subscales include Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. The NASA-TLX is used worldwide to evaluate workload in numerous human-machine systems, or while a human is fulfilling a job, and can be completed in a paper/pencil or computerized format.

The Bedford Workload Rating scale, a modification of the Cooper-Harper rating scale, was originally developed for pilots and uses a unidirectional scale from one to ten (workload insignificant to task abandoned) to rank whether completing a task was possible, if workload was tolerable for the task, and if workload was satisfactory without reduction [66], [67]. Although norms do not exist for the interpretation of this data, [68] provides some recommendations such that a satisfactory workload is recognised when all ratings fall within the range of one to three.

The Rating of Perceived Exertion scale is used to rate perception of exertion during physical activity with regards to how heavy and strenuous the activity feels [51], [69]. It includes overall physical stress, effort, and fatigue, and not any one factor (e.g., leg pain, shortness of breath). The scale ranges from six (no exertion at all) to twenty (maximal exertion) with fourteen points between these end points.

3.2.6 Need for a Customised Aircrew Scale

Customised version of rating scales/questionnaires for aircrew, such as an aircrew-specific Neck Disability Index (NDI), would be helpful for healthcare providers who serve aviators in order to better and more quickly recognise complaints, identify the problem, and monitor the efficiency and effectiveness of treatment. A customised version of a pain rating scale is required due to their occupational challenges in military environment and the need for operational readiness. Higher expectations and needs exist for military aviators regarding medical fitness compared to civilian aviators due the many extreme situations they may face; these range from combat missions requiring helmets with night vision or cuing systems, high-G emergency handling to Survival, Evasion, Resistance, and Escape situations.

A customised pain rating system for aviators should be designed to make it easier to reveal neck issues that should be pursued by designated health care providers in time before the service member needs to be grounded (or temporarily not fit for flight). This would be a useful tool for healthcare providers who serve aviators in order to better and faster recognise their complaints and to better pinpoint the problem so that the most efficient measures can be affected. The NDI does not include any occupation-related neck pain questions and under-reports the severity and disability of flying-related neck pain [43]. Modification of the NDI to reflect flying-related stresses would be valuable, subject to validation.

This could reduce high expenses and downtime due to sick leave, treatment, or simply because the service member needs to be replaced by another service member. However, squadron readiness would most probably not be influenced since other pilots will fly in their stead.

3.3 NECK PAIN QUESTIONNAIRES

3.3.1 Purpose

Questionnaires are often used in aircrew neck pain studies to describe the specific population, determine the extent of the neck pain problem, identify factors associated with neck pain, learn about aircrew's experiences and evaluate interventions (preventive measures and treatments). The military work environment (equipment, technology, etc.) for aircrew is changing and evolving almost continuously as missions, tasks, equipment, technology, and aircraft change and evolve. Since these changes and evolutions definitively have a significant influence on the occurrence of cervical complaints, aircrew neck pain should be monitored at regular intervals to quantify the impact of these changes. Moreover, to successfully address flight-related spinal problems, the changes in military aircrew workspaces and their consequences for spinal pain should be tracked and pooled to provide a larger, more robust dataset to understand the influences on developing neck pain. Therefore, the use of questionnaires should be encouraged among the air forces of all NATO countries.

For purposes explained in the following paragraphs, the NATO HFM-252 RTG devised a set of recommended core questions (Annex D) that should be included in any neck pain questionnaire. Nations are encouraged to use these questions in the exact format presented, as they are the result of many discussions regarding lessons learned from previous work done in this field. The core questionnaire questions are merely a starting point; depending on the goals of the study, additional questions will be required in a questionnaire to investigate other hypotheses. Other topics of interest may include operational/functional impact, healthcare resource utilisation, risk factors, and more detailed questions on demographics, pain characterization, and flight experience. The optional questions themselves are not included in this document; rather suggestions regarding questionnaire design and question utilisation are included, based on lessons learned from earlier survey studies performed by nations represented in NATO HFM-252 RTG. The complete questionnaires including more detailed questions are available upon request from the individual members of NATO HFM-252 RTG.

3.3.2 Neck Pain Definitions and Core Questions

In the current literature, a large variability in the neck pain prevalence rates among aircrew is observed, even in the same aircraft population (Chapter 2). Additionally, results of published survey studies are often not comparable because of using different questions and outcome measures. Especially when different definitions are used for neck pain, adequate comparisons are challenging to make. Minor changes in wording, or even ordering alternatives, can cause differences in responses. Therefore, one of the purposes of NATO HFM-252 RTG was to reach consensus about neck pain and flight-related neck pain definitions, and to identify the core questions (Annex D), so results of future questionnaires may be comparable. Additionally, a set of core questions provides the potential to merge the data to get sufficient numbers for meaningful statistical analyses. The purpose of this NATO RTG was not to develop a comprehensive questionnaire, as the content of a questionnaire depends on the specific objectives of the study conducted. However, by using the core questions, comparable neck pain prevalence rates between nations can be achieved, and more powerful and significant correlations with demographics, physical activity, impact on performance, and flight safety and flight hours (exposure) can be made.

Within NATO HFM-252 RTG, consensus was reached about the following definition of significant neck pain and flight-related neck pain, which was initially proposed by [43], and is used in the core questions (see Section 2.3.4):

- **Significant Neck Pain –** refers to the presence of discomfort that intrudes into one's awareness during usual activities, and has caused one to perform at a lower level, continue despite discomfort, or modify activity to reduce the discomfort. It *does not* refer to trivial mild aches that are easily dismissed and do not affect function.
- **Significant Flight-Related Neck Pain –** refers to significant neck pain that occurs during or within 48 hours after flight. It *does not* refer to pain that is obviously due to other activities or causes.

3.3.3 Developing a Questionnaire

To develop a complete questionnaire, it is recommended to consult other documents [70], [71], [72], [73], [74], [75], because as stated earlier, this is not within the scope of this report. The questions should always address the intended purpose of the questionnaire/study. When phrasing each question, one should have in mind the specific topic the question is measuring and how each question will contribute to the study's objectives. Furthermore, it is critical to pre-determine how a question will be used in statistical analysis, for phrasing, selecting the format of the question and response, and for determining the relevance of the question.

3.3.4 Time Frames

Most aircrew neck pain surveys have utilised questionnaires as part of retrospective and/or cross-sectional studies. The advantage of a retrospective study is that the exposure has already occurred and aircrew need only fill out a questionnaire once. Once the questionnaire is completed, the data can be analysed by the researcher, and results are therefore quickly obtained. However, a disadvantage of retrospective studies is that there is potential for recall bias. It is established in the literature that recall bias can be a significant confounder [76], [77], in particular beyond 12 months [78], [79].

One way to mitigate this is to use questions which limit recall history to 12 months or less. Some of the advantages to a longer history period include potentially higher incidence rates (longer exposure) and that the questionnaire is more likely to capture any variation in operational tempo that may not be accounted for during shorter periods of time.

One of the benefits of prospective studies is that they often remove the issue of recall bias. Arguably one of the most important advantages of prospective studies in the context of this report is (assuming all of the criteria are met) that prospective studies can be used to show causation [80]. However, given that neck pain is understood to be a multifactorial problem, establishing causation of any one variable may still be difficult. A disadvantage of prospective studies is retention rate; drop-out can be a problem and can result in biased results, especially if the reason for loss to follow-up is related to the risk factor or outcome.

Most nations have recognised that neck pain is a significant problem and have begun investigating this using cross-sectional retrospective studies, for all the reasons stated above. This is a reasonable starting point for those nations who have not yet characterised or quantified neck pain in their population. NATO HFM-252 RTG recognises the practical feasibility of a retrospective questionnaire and that one of the limiting factors to compare data between surveys is the chosen time frame. It is therefore recommended to include the twelve-month history of neck pain in all retrospective studies, and add additional questions with shorter/longer time frames if indicated for the specific study. NATO HFM-252 RTG encourages the use of prospective studies whenever possible, especially when the purpose of the questionnaire is to measure the effect of specific changes in work environment (new equipment/aircraft) or interventions (neck pain prevention programs).

NATO HFM-252 RTG recommends conducting broad spectrum surveys of a given population no more frequently than every 5 years. This should be adequate time to allow any changes/interventions at the organizational level to show an effect. For specific interventions, questionnaires should be administered at baseline and again at more frequent intervals. For example, the UK Aircrew Conditioning Programme administers a follow-up questionnaire every 6 months while following the programme. Generally speaking, the frequency of follow-up questionnaires must allow adequate time to allow for a resultant change to take effect and will be unique to each intervention/study protocol.

3.3.5 Administering Guidance

The experience of several nations within this NATO RTG is that aircrews are reluctant to report physical complaints in their military environment due to fear of restriction of flying (i.e., or grounding). It is therefore advisable to consider carefully the way in which questionnaires are administered. Guaranteeing anonymity is an essential requirement. It should also be emphasized to the aircrew that only group results will be presented and that individual data will not be included in their medical file. Note that it is often the case that approval from an Institutional Review or Ethics Board is required prior to distributing a questionnaire.

A clear explanation of the study is essential to elicit support and participation from the aircrew. The explanation should be provided in both written and oral formats, include what the data will be used for, and how the study results/deliverables will benefit the aircrew. Ideally, this explanation/introduction of the questionnaire will be provided in person by a trusted source, such as a uniformed flight surgeon, physiotherapist, or trusted researcher. The experience of the members of the NATO panel who have administered questionnaires in recent years is that this approach has been very effective to elicit a strong survey response. For example, a survey of RCAF helicopter aircrew that was not administered in person achieved a 55.5% (233/420) response rate [81]. Whereas, [82] used a digital questionnaire (Limesurvey), but gave an in-person explanation during a pilot meeting and achieved a response rate of 74.8% (71/95) in F-16 pilots. Two later efforts saw even higher participation rates; 85.4% (88/103) in RCAF fast jet pilots [83] and 97.5% (78/80) in Belgian F-16 pilots participating in Operation Desert Falcon [84]. RAAF survey of 140 fast jet aircrew reported an 82% response rate using a paper survey administered during a defined window of opportunity when aircrew were most likely to attend (e.g., during a command brief aiming for maximum attendance) [43].

Questionnaires can be administered via traditional paper or online survey software tools. The advantage of paper is that it can be distributed and collected immediately, but this requires that all participants be present and this can be challenging. One important benefit of online survey tools is that the questionnaire is accessible from everywhere; at home or work; only an internet connection is required and the survey can be completed at the leisure/pace of the participant. This is very useful when the intended population are pilots, as they are rarely working all together in the same place at the same time. Moreover, when it comes to data analysis, online survey data can be exported directly to the chosen statistical programme, thereby simplifying the analysis. The disadvantage is that there is often no immediate (face-to-face) interaction with the survey administrator if various questions arise from the questionnaire, and there is a greater probability for lower completion rates.

Aircrew are regularly asked to complete questionnaires and can be reluctant to participate unless the value is clearly described to them. It is important to keep the operational community apprised of the research results once analysed and ready for distribution. By gathering contact information of those participants who wish to receive the results of the study directly, the researcher can close the loop in communicating the results and the benefits of participating in the study back to the operational community in a timely manner, thus, reinforcing the benefits of participation in future work.

3.3.6 Core Questions

Several of the questions request specific numerical values, such as age at the time the questionnaire is filled out. The rationale for this phrasing is that it enables parametric statistical analysis, which is preferred for stronger statistical inference. However, if the data are non-normally distributed, then responses can be binned into intervals, e.g., 21 – 25 years, 26 – 30 years, etc., for non-parametric analysis techniques.

3.3.6.1 Demographic Information

A primary reason for collecting demographic information is to describe the population in terms of age, sex, size, occupational position (flying and non-flying), and aircraft type. Furthermore, the outcome of some of the demographic questions can be included as an independent variable and/or as a confounding factor in the analyses to identify risk factors for neck pain.

3.3.6.2 Physical (In)activity

The purpose of the physical (in)activity core questions is to describe the population in terms of inactivity as well as activity level. One very important variable that has become evident in recent research is the number of hours spent sitting as a risk factor for neck pain [85]. Furthermore, the outcome can be included as independent variable in the analyses to identify risk factors of neck pain.

3.3.6.3 Flight-Related Neck Pain

The purpose of the flight-related neck pain questions is to estimate the prevalence, describe the extent of significant flight-related neck pain, and identify the impact on flight safety. Furthermore, the outcome of the neck pain question can be included as dependent variable in the analyses to identify risk factors of neck pain. Therefore, it is essential that all aircrew, both with and without neck pain, be encouraged to participate in a questionnaire study. To be able to identify risk factors of flight-related neck pain, the information of the aircrew without neck pain is as important as the information of the aircrew with neck pain.

3.3.6.4 Flight Experience

The purpose of the flight experience questions is to describe the exposure and experience of the population in terms of flying hours, specific aircraft flying hours, and the use of head-borne equipment. Furthermore, the outcome of these questions can be included as independent variable in the analyses to identify risk factors of flight-related neck pain. Flight experience data is often, especially in small air forces, not found to be significantly related to neck pain as pilots within the same air force are following the same pilot training, are restricted to the same yearly flying hours, and are using the same equipment. However, this information might be of great interest in the future when data of different nations will be merged. RAAF found that aircrew recollection of flying experience is highly correlated to logged flight hours. Reporting errors were balanced, did not affect group means, and represented only ~ 2% of the corresponding total logged flying experience [86], [87].

3.3.7 Beyond the Core – Suggestions for Optional Questions

3.3.7.1 Demographic Information

Anthropometrics may be a contributing factor to neck pain, although this has not yet been proven. For populations who fly aircraft with smaller cockpits (in particular those with less headroom), height or sitting height may be an important factor to consider.

Elevated Body Mass Index is not always an accurate predictor of fitness/wellness (the ratio of waist circumference to height is known to be more accurate [88] but, generally speaking, elevated BMI (weight to height ratio) is known to be associated with poor physical fitness and diseases such as diabetes, hypertension, heart disease, etc. Poor physical fitness is known to be associated with increased neck/back pain [89], therefore, including height and weight in questionnaire when able can help determine if poor physical fitness is a contributing factor to neck pain in a given population.

Questions regarding nationality are useful in multinational studies. Be wary of reporting this statistic in units where there may be foreign exchange students/staff who could be identified if they are the only one of their nationality involved in the study. There could also be national sensitivities, if for example it appears that nations are being compared, and potentially portraying a nation in an unfavourable light.

3.3.7.2 Flight-Related Neck Pain Occurring Prior to the Previous Twelve Months

In addition to what are considered to be core questions, asking if one has ‘ever experienced significant neck pain in the past twelve months’ (i.e., not flight-related neck pain) will allow those who have no pain to move on to the next section of the questionnaire quickly. This will also identify those who may have neck pain that is pre-existing or not related to flying at all. A major risk factor for developing neck pain is previous neck pain. If you are interested in history of neck pain prior to the most recent 12 months, then it is important to ask if one has ‘experienced significant neck pain prior to the previous 12 months.’

If interested in the short-term prevalence, then it is appropriate to include a question which combines that asked in the core questionnaire (12-month prevalence) with short-term (3-month) prevalence. The NATO HFM-252 RTG defines chronic neck pain as that pain which is present longer than 3 months (see Chapter 4, Section 4.5.5); depending on the goals of the study, it may be useful to distinguish between acute (< 1 week), sub-acute (1 week < 3 months) vs. chronic pain (> 3 months) history.

The most important aspect of choosing the time period over which to ask subjects to report pain is to ensure that is consistent throughout the questionnaire. The pain related questions must use the same reporting time frame as the flight hours questions and all of the other potential contributing factors questions.

A question that asks how frequently one experiences pain provides additional information regarding the impact of the pain. The more often episodes occur, the more likely that it will have a significant impact on function. There will be some variation in the frequency intervals used in each study (depending on study objectives), but common intervals are:

- One episode only (ever);
- Multiple episodes (regular or irregular intervals); and
- Sustained (persistent pain and/or near continuous).

It is very useful (for clinicians in particular) to understand if reported neck pain is a generalized neck pain or associated with a more specific location – back (nape) of neck, right or left side, or is associated with specific neck movements – flexion, extension, right or left lateral flexion, right or left neck rotation, or opening/closing the jaw. A body diagram may be useful to help respondents identify the different parts of the body if they are not familiar with anatomical terms.

Quantifying pain is very difficult, but also very important. If in paper form, the VAS (Section 3.2.1.2) is a well-validated method to quantify pain as a continuous variable [26], [27], which uses a 100 mm line and converts this value into a number. Online surveys/apps will use slider type questions to convert this response into a number; the concern with slider questions is that the initial position of the slider can affect the response (far left vs. far right vs. centred). This type of question is ONLY useful when doing a before/after intervention, otherwise the question cannot be internally validated. This question can be applied to TYPICAL or WORST episode of pain.

Asking a question about whether one's pain has changed significantly over the past 12 months will capture the pain that may be related to seasonal/cyclic flying schedules that may not be otherwise captured in a standard 12-month period.

Recall bias is a significant confounder in surveys. Three-month flying history is more reliable than twelve months. However, if units have a cyclical flying schedule (e.g., night flying for 2 – 3 weeks every 6 months), then that type of flying/exposure would not be captured in the three-month history. Including questions about differences in the type of flying beyond the past three months will capture other exposures which may have a significant impact on symptoms.

Finishing each section with an open-ended question, such as 'is there anything else that you would like to share regarding your flight-related neck pain?' can be useful, but there are disadvantages to this type of question. Open-ended questions which allow respondents to provide free text answers provide more qualitative data. This will help provide a better understanding of any trends or confounders in the data. However, this type of response is much more time intensive and difficult to analyse. For large study populations, open-ended/free text questions are not recommended unless there are resources dedicated to data analysis on a larger scale.

3.3.7.3 Risk Factors for Neck Pain

There are a variety of potential risk factors which may be related to neck pain. If a goal of the survey is to determine potential associations / causal factors of neck pain, then it is useful to ask questions about exposure to that particular risk factor. Potential factors to consider include (but are not limited to):

- Head-borne equipment exposure such as Joint Helmet-Mounted Cuing System (JHMCS);
- Prior injury;
- Timing of flying vs. pain onset (flying hours when pain first begin, sortie length before pain begins, consecutive days of flying before pain begins, etc.);
- Sortie profile (type, length, frequency);
- G exposure (frequency, duration, intensity, body position);
- NVG exposure (frequency, duration);
- Survival Vest (weight, configuration/contents and interaction with other life support equipment, such the helmet and harness and/or flight controls, such as the throttle);
- Harness (weight, configuration and interaction with other life support equipment, including the ejection seat); and
- Psychosocial (mental fatigue, irritability, mood, etc.).

As survey data is primarily subjective, it is important to design questions in a way to anticipate potential answers and how the data will be used in analysis. Sliding scale / numerical scale questions are helpful to quantify subjective responses, in particular for those questions which ask one's 'experience' or 'opinion.' An example of this type of question is 'To what extent does the amount of flying you do contribute to your neck pain?' A sliding scale anchored by 'Not at all' on one end and 'Completely' on the opposite end allows the respondent to choose a response somewhere along the spectrum. Similar to a VAS scale, this response can be measured and a numerical response recorded.

3.3.7.4 Functional and Operational Impact of Neck Pain

This section of questions is applicable if a goal of the survey is to determine the functional and/or operational impact of neck pain. One of the most important aspects of clinical assessment of aircrew is determining aeromedical disposition. This can be challenging because the clinician must understand how the presence and severity of symptoms impacts aircrew function and their resulting ability to complete tasks in a safe and timely manner.

It is widely known that that neck pain is often unreported in clinical settings. This is a result of (aircrew) fear of being grounded by a clinician. Consequently, the symptoms go unreported for long periods of time (while the aircrew continue to fly) until in many cases, the condition progresses to the point that grounding is required. Generally speaking, aircrew are responsible individuals, cognisant of their symptoms and impact on function and will 'self-ground' when things reach the point where they no longer feel confident in their own ability to operate an aircraft safely. These are the signs and symptoms which clinicians need to become familiar with in order to make decisions regarding aeromedical disposition.

One of the primary roles of aviation medicine clinicians is to preserve the health of the 'fighting force.' This includes preventive medicine / public health practices as well as flight safety considerations for both the individual and the mission. A clinician who is not familiar with the flight environment or the injury pattern in question will often err on the side of caution. This may result in the clinician imposing medical employment limitations (such as G or helmet-mounted devices exposure) or grounding aircrew who present with neck pain but may still be safe to conduct flight operations while undergoing treatment. Questions on this topic should be designed to better understand which symptoms have significant impact on personal and professional function, and the ability to conduct safe flight operations.

From a resource management perspective, it is also important to understand which health care resources are being utilised to manage neck pain, which management strategies / treatment modalities are being implemented, and which are effective or not. Questions which ask about which health care professionals, investigations, and treatment modalities have been accessed during the management of neck pain are designed to elicit this information and are helpful to determine the impact of neck pain on healthcare resources.

Aircrew are advised during many stages of their training and flying careers that they are not permitted to take medications without the advice of a Flight Surgeon or other qualified Aviation Medicine Provider. Flying while taking medications not approved for use during flight operations represents a flight safety concern. The extent to which aircrew are self-medicating and/or seeking assistance from a non-aviation medicine provider demonstrates the severity of the injury/pain.

The operational impact of illness/injury is arguably the most important piece of information to an individual and certainly to a Commander. If aircrew are not able to fly, or must fly with restrictions, this impacts the mission (as well as the individual), at the tactical level and on a larger scale, at the strategic level. Understanding how many flying days are lost due to neck pain demonstrates the operational impact to the individual, at the tactical and operational level. Understanding how many careers are cut short due to neck pain demonstrates the operational impact to the 'Fighting Force' on a strategic level. Gathering this information can help form a 'business case' to the operational leadership regarding the impact of neck pain and justification to proactively fund and support preventive/mitigation strategies.

3.3.7.5 Pain Reduction/Prevention Strategies

Much work is being done to find interventions which will mitigate and ideally prevent (or at least delay onset) of neck pain. As interventions are trialed/implemented, it is important to follow-up and determine if that intervention has caused a significant change (positive or negative) in outcome measures. If no interventions are yet in place, this question is a useful tool to quickly determine what methodologies may already be in use in a given population.

One of the most common barriers to fielding exercise programmes and similar treatment modalities is compliance. Available time / prioritising time is the most common reason study participants provide when asked for reasons to explain non-compliance. Including a question which asks 'Would you be more likely to consistently follow an exercise programme (including neck conditioning exercises) if you were provided with time to do the exercises during your normal work day?' will gauge the level of willingness to follow a programme, if time during the workday is no longer a barrier. This will help guide future work and what level of compliance could be expected from the operational community.

3.3.7.6 Impact of Pain on Flight Safety

The operational impact of neck pain is difficult to quantify. Ideally, aircrew will seek help prior to the symptoms progressing to the point that their function is significantly impacted to the point of becoming a flight safety issue.

In addition to what are considered to be core questions, collecting information regarding whether neck pain has impacted flight safety will help determine is neck pain is a causal factor in flight safety incidents in a given population, which may not be reported elsewhere.

3.4 OBJECTIVE MEASURES

3.4.1 Strength, Endurance, Range of Motion, Functional Assessment

3.4.1.1 Aircrew Conditioning Programme (ACP) Objective Measures

A good example of an application of strength, endurance, range of motion, and functional assessment measures currently deployed can be found in the Aircrew Conditioning Programme (ACP). The ACP is a practical programme to enhance aircrew performance through improvements in the ability to repeatedly perform an effective Anti-G Straining Manoeuvre (AGSM) and reduce strain injuries to the neck. It incorporates well-established exercise and conditioning techniques with measurable outcomes which are used to provide individualised training programmes for each aircrew, and can help assess the severity and effects of neck pain.

Assessment is conducted by a physiotherapist and an ACP Instructors Course qualified Physical Training Instructor (PTI), occurring at the start of each stage of the flying training pipeline and every six months thereafter. The results of all assessments are used to provide individualised training programmes for each aircrew.

3.4.1.1.1 Neck Range of Motion

Neck Range of Motion is measured with a Cervical Range of Motion (CROM) device to determine active cervical range of motion in the sagittal plane (flexion and extension), frontal plane (lateral flexion), and transverse plane (rotation). CROM is measured in a sitting position with the spine in neutral alignment. The outcome measure is the maximum active range of motion in each direction. The reliability of the CROM has been rated positively for intra-observer (Intra-class Correlation Coefficient (ICC) = > 0.85 – 0.98), inter-observer (ICC = > 0.70, 0.82 – 0.95), and construct validity was $r > 0.65$ [90], [91].

3.4.1.1.2 Neck Isometric Strength

Neck Isometric Strength is measured with a manual load cell (e.g., Lafayette push load cell) while performing three repetitions of a 5 second Maximal Voluntary Contraction (MVC) with 30 seconds recovery between each contraction. Measurements are taken in flexion, extension, lateral flexion (left and right), anterolateral flexion (left and right), and posterolateral flexion (left and right) directions. Isometric strength is measured in a seated position in a neutral spinal alignment with hands crossed across the chest. The outcome measure is the maximum load for each direction. Increased neck muscle strength is suggested to protect and stabilise the head and neck muscles during brief episodes of increased loading as a result of +Gz exposure. Fighter pilots with frequent episodes of neck pain have comparatively lower neck extensor strength. While EMG does not directly measure strength, when measured concurrently and calibrated with MVC, relative changes in signal amplitude can provide insight into muscle response. EMG results in a study with for helicopter pilots with neck pain led authors to hypothesize that altered muscle activation might reflect impaired muscle functioning rather than lower local muscle fatigue [92].

3.4.1.1.3 Functional Movement Screening (FMS)

FMS is comprised of seven specific movement patterns that require a balance of mobility and stability, which is used to identify functional limitations and asymmetries. The outcome measure is the maximum score achieved.

FMS demonstrates good inter-rater reliability (ICC = 0.89 – 0.87) and intra-rater reliability for all raters regardless of education or previous experience with FMS (ICC = 0.81 – 0.91) [93]. Movement efficiency and control are built on key-contributing determinants of stability (strength, neuromuscular control, and endurance) and functional mobility of the kinetic chain. Muscle imbalances, inadequate core stability, and altered kinematics due to fatigue and/or muscle strength imbalances can readily lead to dysfunctional neuromuscular control, impaired movement patterns, and increased risk for musculoskeletal injury [94].

3.4.1.1.4 Running-Based Anaerobic Sprint Test (RAST)

RAST was adapted from the Wingate Anaerobic Test (WAnT) protocol as a tool to assess repeated sprint ability and power. RAST involves completion of 6 times 20 m maximal effort discontinuous sprints, with 10 second turnaround between each sprint. Fatigue index and power output are calculated from the sprint times. RAST had significant correlation with the Wingate test and allows for movements more specific to events with running, is easily applied, and is low cost [95]. Peak blood lactate values are similar between RAST and WAnT [96].

3.4.1.1.5 One Repetition Maximum Test

The One Repetition Maximum Test is used to measure muscular strength and endurance of some of the most important muscles for the AGSM. Outcome measures are maximum weight (in kg) of a single repetition of double leg press (leg muscles), bar bell flat bench press (chest muscles), and timed plank to failure (sub-maximal endurance measure of core/abdominal muscles – lying on front with forearms on the ground, keeping elbows under shoulders and feet together, then raise the body upward off the floor and hold this position with the body in a straight line). Improvements in strength or muscle endurance (or both) of the large muscle groups recruited during the AGSM might enhance G tolerance if fatigue of these muscles were a limiting factor Air Combat Manoeuvre (ACM) tolerance time [97].

3.4.1.2 ACP Components

The ACP consists of four main components:

1) **Whole-body flexibility and mobility** involve exercises in specific movement patterns that require a balance of mobility and stability. General stretching and foam rolling to main muscle groups are also used.
2) **Cardiovascular Fitness** focusing on anaerobic capacity, with sessions involving a combination of weighted whole-body exercises and high-intensity cardiovascular exercises.
3) **Stabilisation and Motor Control** for the neck, shoulder girdle, and lower back. Exercises begin with maintaining a neutral posture in all positions, through static rotation control, to dynamic rotation control on a stable base, and then on an unstable base.
4) **Strengthening Exercises** of the neck, back, abdominal, and leg muscles, incorporating isometric neck strengthening and Olympic type lifting exercises. Aircrew develop initial technique instruction and competency, prior to progression of weight. Neck strengthening exercises are performed isometrically in a spinal neutral position with a head harness. There are four levels of exercise which are designed to activate segmental stabilisers, then global stabilisers, and then global movers. Relatively low loads are used (1 – 3 kg), with weights increased for upper body movements.

3.4.2 Imaging Uses and Limitations

Cervical spine disorders are common conditions in pilots. Fighter pilots report neck pain due to high +Gz forces, helicopter pilots due to vibrations and high loads of helmet-mounted devices [98], [99], [100]. While the use of radiological x-ray has been limited because of the associated radiation exposure, MRI is considered safe in this respect. So, MRI for neck pain is appealing but the studies and meta-analysis so far do not support this idea, if none of the “red flag” reasons exist (see Chapter 4.3.3.4).

Landau et al. [101] did not find a higher rate of cervical spine degenerative changes in fighter pilots or helicopter pilots, despite their exposure to high loading of the cervical spine. Occupational exposure to acceleration in fighter aircraft did not cause significant radiological changes in the spinal column during the first thirteen years of a fighter pilot’s flying career [102]. In the latest systematic review and meta-analysis, [103] showed no differences in the prevalence of cervical or lumbar pain or radiological degeneration between fighter pilots and helicopter or transport/cargo pilots, or non-flying personnel. They could not find an association between exposure to G forces and cervical disc degeneration. On the other hand, there is a high prevalence of cervical changes in asymptomatic individuals (pilots exposed to high Gz forces and controls) [104].

3.4.3 Pain and Stress Measures

Pain symptoms are often manifested in a physiological stress response due to discomfort and anxiety from operational performance challenges. Although not all measures of stress are appropriate for pain, measures of stress including heart rate, heart rate variability, respiration rate, blood pressure, galvanic skin response, and blood biomarkers, are used in aviation physiological monitoring given that stress can have implications for performance, and thus safety.

3.4.3.1 Heart Rate

Heart rate is the number of times the heart beats, or contracts per minute, which indicates the body’s state of physical need (e.g., oxygen absorption, carbon dioxide excretion) and arousal (e.g., stress, excitement). While abnormal resting heart rates for adults, below 50 or above 100 beats per minute (bpm), can indicate a state of disease, changes in heart rate can be very informative for both clinicians and researchers. Numerous factors that can affect heart rate include stress/pain, body temperature, eating/digestion, exercise, caffeine intake, illness, medications, age, sex, etc., [105], [106], [107].

Heart Rate Variability (HRV): HRV measures provide an indication of the relative contributions of the Sympathetic Nervous System (SNS) and parasympathetic nervous system in the autonomic control of the heart [108], [109]. There are numerous different indices of HRV which provide different information regarding the beat-to-beat variability, and thus provide more complex information regarding the effects of painful stimuli [110], [111]. Pain causes an increase in electrical pain signals in the SNS and a release of adrenaline from the adrenal gland, both of which cause an increase in heart rate, sympathetic driven HRV measures, and blood pressure [112], [113].

3.4.3.2 Blood Pressure

Blood pressure is the pressure of circulating blood on the walls of the blood vessels and is characterized as normal resting by a reading of 120/80 mmHg (millimetres of mercury systolic/diastolic). Acute pain can result in quick increases in blood pressure, due to increases in peripheral resistance, heart rate, and cardiac stroke volume, as well as hypothalamic-pituitary-adrenal axis activation of the adrenal glands [112]. Increases in blood pressure are also prevalent in individuals with chronic pain [114].

3.4.3.3 Respiration Rate

Respiration rate is the number of breaths taken per minute and, similar to heart rate and heart rate variability, is an indicator of the body’s state of physical need and arousal. Normal respiration for adults is 12 – 20 breaths per minute, whereas abnormal rates of below 12 or above 25 are indicative of stress/agitation, pain, fever, illness, medical conditions, etc., [110], [115].

3.4.3.4 Galvanic Skin Response

Galvanic Skin Response (GSR), also termed Electrodermal Activity, is a measure of active and passive electrical properties (electrical resistance) of the skin, which varies with the state of sweat gland activity in the skin [116]. Given that sweating is controlled by the SNS, increases in skin conductance, as a result of increased sweat gland activity, is indicative of increased psychological and/or physiological arousal. While GSR is not regularly used to clinically assess stress levels, research utilises this measure as it provides a relative change in arousal levels over a period of time (e.g., flight duration, experimental protocol) which is helpful when correlating to subjective ratings (e.g., discomfort, pain) and other measures of stress [117], [118].

3.4.3.5 Blood Biomarkers

Neuroendocrine and immune biomarkers circulating in the blood or measurable in saliva or urine can be used as indicators of the level of stress, illness, and/or pain [113], [119], [120], [121], [122]. Following pain stimulation, an elevation in adrenal (i.e., cortisol, pregnenolone, dehydroepiandrosterone), gonad (i.e., testosterone, progesterone, estrogen), and thyroid (i.e., triiodothyrone, thyroxine) hormones occurs [113]. Inflammatory cytokines, such as C-reactive protein, tumour necrosis factor-alpha, and various interleukins are used as markers of the severity and type of pain, with some being specific to certain medical conditions [121], [123], [124]. Changes in these biomarkers can be indicative of the severity and duration of pain, and can also provide clinicians with information regarding changes in health/pain status.

3.4.4 Surface Electromyography Standards

The intent of this section is to provide summary guidance and recommendations for surface Electromyography (sEMG) use in neck pain research, with the goal of synchronizing techniques and data analysis to maximise knowledge transfer between researchers who wish to perform similar studies to those performed by HFM-252 RTG members.

Detailed analysis and/or mathematical reasoning of the various topics under discussion are beyond the scope of this section, and have been covered in detail in the literature through individual reports [125], [126], [127], [128], [129], and international collaborative efforts, such as the Surface Electromyography for Non-invasive Assessment of Muscles (SENIAM: www.seniam.org) project as well as the International Society of Electromyography and Kinesiology (ISEK: www.isek-online.org). The SENIAM project was a European concerted action to integrate basic and applied research on sEMG in order to provide summary guidance for the European research community. SENIAM outlined standards for sensor size, composition, placement (on the muscle and inter-electrode distance), and fixation. The International Society of Electrophysiology and Kinesiology is a multidisciplinary group founded to develop interdisciplinary collaborations and knowledge sharing. As comprehensive reviews of sEMG, the standards and recommendations published by the SENIAM project and ISEK are generally accepted as the norm throughout the research community.

Although standards are outlined for reference location, electrode placement and alignment, etc., some flexibility may be required in an aviation environment where individuals are wearing flight suits, protective gear, and ALSE. To confirm electrode placement, interference issues under clothing, skin impedance [130], etc., clinical manual manipulation muscle tests should be conducted and confirmed in the recording. At a minimum, the following muscles are recommended for bilateral instrumentation during research related to neck pain: upper trapezius, splenius capitis, and the sternocleidomastoid. A sampling frequency of 1024 Hz is desirable. The only hardware filter recommended is a standard bandpass filter (10 – 500 Hz) to avoid anti-aliasing effects. Notch filtering of sEMG data is not acceptable for scientific studies per SENIAM and ISEK guidelines due to the amount of data being removed, though challenges in collecting sEMG in noisy environments, such as with aircraft noise and electromagnetic interference, may require additional signal conditioning. Other challenges of collecting sEMG in an aviation environment include vibration, noise, movement, equipment (e.g., ALSE, helmet), airworthiness considerations, and egress.

Surface EMG is used to record muscle activity dynamically during simulated operational actions and during stand-alone strength assessments. Regardless of the ultimate goal of using the sEMG, it is important to normalise the data, allowing for comparisons between muscles, trials, and participants. One of the most common means of normalisation is via MVC. Normalising sEMG readings using MVC provides a context for muscle activity/activation relative to a maximal effort. While MVC normalisation is the easiest and preferred method, the nature of MVC testing makes it unsuitable for use in patients with neck pain or injury due to the unlikelihood of a true maximum effort production and/or the risk of causing further pain injury to the participant. Besides MVC normalisation, other methods of data normalisation that have been used and discussed in the literature, including known sub-maximal contraction, task-specific contraction, and newly discussed amplitude normalisation [127], [129].

Traditional techniques of analysis, such as sEMG amplitude (peak, mean, area), for relative activation, power spectrum analysis for fatigue, and zero crossings for on/off timing are all well documented in the literature [125], [128], [129], [131], [132], [133]. In addition, as an indicator of muscle fatigue, defined by an increase in EMG amplitude and a decrease in median frequency, the change in these two measures can be calculated to indicate a change in fatigue over time [125]. EMG analysis is helpful for estimating muscle activity, relative fatigue, and strength (when calibrated using MVC); however, there is no evidence that EMG can be used as a pain metric. Although EMG activity levels change concurrently with increases in various metabolites (e.g., creatine kinase, Na^+-K^+ pump activity) that are associated with delayed onset muscle soreness and eccentric muscle contraction [134], [135], [136], [137], the types of muscle contractions and responses are not indicative of an increased risk for injury. It can be argued that the relationships reported between EMG, delayed onset muscle soreness, and eccentric muscle contractions may be occurring in aviation environments when head-supported mass is utilised. However, such studies have focused on the quadriceps and elbow flexor muscles, whereas no studies known to date have specifically examined neck muscle activity levels in relation to neck pain and injury thresholds.

3.5 RECOMMENDATIONS

Recommendation 3.1 (Section 3.1.2): Use of any model must be applied only for the conditions in which the model was validated. To determine its relevance to provide design guidelines for military purposes, users must know if the following apply to the question being asked (e.g., will this reduce neck pain incidence):

- Input data;
- The conditions the data were obtained under (temperature, humidity, loading magnitude, direction, onset rate, profile, etc.);
- Applicability to the population of interest (sex, age);
- Relevant loading vectors and postures;

- Appropriate use of animal surrogate data (scaling);
- Number of specimens used;
- The limitation of PMHS use for dynamic testing in which muscles are not active; and
- The availability of military-relevant validation data.

Recommendation 3.2 (Section 3.2.6): In order to close a gap in the ability to quantify aircrew pain and compare amongst aviators, development and validation of customised rating scales for aircrew, such as an aircrew-specific Neck Disability Index, would be helpful for healthcare providers who serve aviators in order to better and more quickly recognise complaints, identify the problem, and monitor the efficiency and effectiveness of treatment.

Recommendation 3.3 (Section 3.3.1): It is clear from the review in Chapter 2 of surveys that it is challenging to combine this data in meaningful ways. It is recommended that surveys are undertaken in a way that will allow for data to be consolidated across nations to increase statistical power, and facilitate population comparisons. Therefore, the NATO HFM-252 Aircrew Neck Pain Questionnaire should be included in all questionnaires to survey neck pain in an aircrew population. See Annex D for the NATO HFM-252 Aircrew Neck Pain Questionnaire for the recommended wording and format.

Recommendation 3.4 (Section 3.3.4): Questionnaires should include the twelve-month history of neck pain in all retrospective studies, and add additional questions with shorter/longer time frames if indicated for the specific study. NATO HFM-252 RTG encourages the use of prospective studies whenever possible. If the purpose of the questionnaire is to measure the effect of specific changes in work environment (new equipment/aircraft) or interventions (neck pain prevention programmes), a prospective study should be used.

Recommendation 3.5 (Section 3.3.4): Conduct broad spectrum surveys of a given population no more frequently than every 5 years. This should be adequate time to allow any changes/interventions at the organizational level to show an effect. For specific interventions, questionnaires should be administered at baseline and again at more frequent intervals.

Recommendation 3.6 (Section 3.4.2): Besides the discussion about red flags in neck pain where imaging is an absolute necessity (see Chapter 4.5.1), if the sole symptom is acute neck pain, immediate imaging is not recommended due to the fact that MRI is expensive and there is only a limited correlation with the pain in most cases. Baseline imaging before high-G exposure is beneficial in order to evaluate later possible changes during the aircrew's career. Routine MRI follow-ups are not recommended for aircrew and it is suggested that the need for imaging be based on clinical outcome.

Recommendation 3.7 (Section 3.4.4): Procedures and conventions recommended in this report for the collection and analysis of EMG data should be followed by NATO neck pain researchers to facilitate collaboration and exchange of data.

3.6 REFERENCES

[1] Farrell, P.S.E., Tack, D.W., Nakaza, E.T., Bray-Miners, J., and Farrell, C.M. (2014). Combined task and physical demands analyses towards a comprehensive human work model. Paper presented at the HFES 2014 Annual Meeting, Chicago, IL.

[2] Yoganandan, N., Pintar, F.A., Stemper, B.D., Baisden, J.L., Aktay, R., Shender, B.S., and Paskoff, G. (2006). Bone mineral density of human female cervical and lumbar spines from quantitative computed tomography. Spine (Philadelphia, PA, 1976), 31(1), 73-76.

[3] Yoganandan, N., Pintar, F.A., Stemper, B.D., Baisden, J.L., Aktay, R., Shender, B.S., … Laud, P. (2006). Trabecular bone density of male human cervical and lumbar vertebrae. Bone, 39(2), 336-344. doi: 10.1016/j.bone.2006.01.160.

[4] Bass, C.R., Planchak, C.J., Salzar, R.S., Lucas, S.R., Rafaels, K.A., Shender, B.S., and Paskoff, G. (2007). The temperature-dependent viscoelasticity of porcine lumbar spine ligaments. Spine (Philadelphia, PA, 1976), 32(16), E436-442. doi: 10.1097/BRS.0b013e3180b7fa58.

[5] Stemper, B.D., Yoganandan, N., Pintar, F.A., Shender, B.S., and Paskoff, G.R. (2009). Physical effects of ejection on the head-neck complex: Demonstration of a cadaver model. Aviat Space Environ Med, 80(5), 489-494.

[6] Nguyen, H.S., Doan, N., Shabani, S., Baisden, J., Wolfla, C., Paskoff, G., … Stemper, B. (2016). Upright magnetic resonance imaging of the lumbar spine: Back pain and radiculopathy. Journal of Craniovertebral Junction and Spine, 7(7), 31-37.

[7] Francis, W.L., Eliason, T.D., Thacker, B.H., Paskoff, G.R., Shender, B.S., and Nicolella, D.P. (2014). Implementation and validation of probabilistic models of the anterior longitudinal ligament and posterior longitudinal ligament of the cervical spine. Computer Methods in Biomechanics and Biomedical Engineering, 17(8), 905-916.

[8] Hill, A.V. (1938). The heat of shortening and the dynamic constants of muscle. In: Proceedings of the Royal Society B, 126(843), 126-195.

[9] Pollock, R., Puxley, K., and Llewellyn, M. (2017). An investigation of a software for interactive musculoskeletal modelling (SIMM) methodology to assess muscle force output in response to variations in helmet mass properties and Gz. United Kingdom: QINETIQ/17/00044, QINETIQ.

[10] Pollock, R.D., Pulford, D., Firth, R.V., Tank, H.R., and Stevenson, A.T. (2018). Assessments of the validity of SIMM to estimate muscle activation during simple and aircrew representative head movements. United Kingdom: QINETIQ/18/01752, QINETIQ.

[11] Cazzola, D., Holsgrove, T P., Preatoni, E., Gill, H.S., and Trewartha, G. (2017). Cervical spine injuries: A whole-body musculoskeletal model for the analysis of spinal loading. PLOS ONE, 12(1), e0169329. doi: 10.1371/journal.pone.0169329.

[12] Shender, B.S., Paskoff, G., Askew, G.K., Coughlan, R., and Isdahl, W. (2001). Determination of head/neck loads during maneuvering acceleration. International Journal of Crashworthiness, 6, 585-604.

[13] DOD. (1999). Department of Defense (DOD): Human Engineering Program Process and Procedures. Retrieved from http://quanterion.com.

[14] Miller, R.B. (1953). A method for man-machine task analysis. WADC Technical Report 53-137, Wright-Patterson Air Force Base, Dayton, OH.

[15] Whitley, P., Zhou, A., Chen, G., Wu, F., Chen, Z., Przekwas, A., … Shender, B. (2013). A model for back pain prediction and mitigation in military pilots and vehicle occupants. Aviat Space Environ Med, 84(4), 285.

[16] Henninger, H.B., Reese, S.P., Anderson, A.E., and Weiss, J.A. (2010). Validation of computational models in biomechanics. Proc Inst Mech Eng H, 224(7), 801-812. doi: 10.1243/09544119JEIM649.

[17] Thacker, B.H., Francis, W.L., and Nicholella, D.P. (2007). Model validation and uncertainty quantification applied to cervical spine injury assessment. In: Computational Uncertainty in Military Vehicle Design. Paper presented at the RTO-MP-AVT-147, Neuilly-sur-Seine, France.

[18] Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., and Jørgensen, K. (1987). Standardised Nordic questionnaire for the analysis of musculoskeletal symptoms. Applied Ergonomics, 18(3), 233-237.

[19] Palmer, K., Smith, G., Kellingray, S., and Cooper, C. (1999). Repeatability and validity of an upper limb and neck discomfort questionnaire: The utility of the standardized Nordic questionnaire. Occup Med (London), 49(3), 171-175.

[20] Bolton, J.E., and Humphreys, B.K. (2002). The Bournemouth Questionnaire: A short-form comprehensive outcome measure. II. Psychometric properties in neck pain patients. J Manipulative Physiol Ther, 25(3), 141-148.

[21] Linton, S.J., and Boersma, K. (2003). Early identification of patients at risk of developing a persistent back problem: The predictive validity of the Orebro Musculoskeletal Pain Questionnaire. Clin J Pain, 19(2), 80-86.

[22] Linton, S.J., and Hallden, K. (1998). Can we screen for problematic back pain? A screening questionnaire for predicting outcome in acute and subacute back pain. Clin J Pain, 14(3), 209-215.

[23] Van Damme, B. (2015). Optimizing physical and psychosocial assessment in patients with non-specific chronic low back pain. (Doctor of Philosophy), Ghent University, Brussels, Belgium.

[24] McHorney, C.A., Ware, J.E., Jr., and Raczek, A.E. (1993). The MOS 36-item short-form health survey (SF-36): II. Psychometric and clinical tests of validity in measuring physical and mental health constructs. Med Care, 31(3), 247-263.

[25] Ware, J.E., Jr., and Sherbourne, C.D. (1992). The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med Care, 30(6), 473-483.

[26] Jensen, M.P., Karoly, P., and Braver, S. (1986). The measurement of clinical pain intensity: A comparison of six methods. Pain, 27(1), 117-126.

[27] McCormack, H.M., Horne, D.J., and Sheather, S. (1988). Clinical applications of visual analogue scales: A critical review. Psychol Med, 18(4), 1007-1019.

[28] Portenoy, R.K., and Tanner, R.M. (1996). Pain Management: Theory and Practice: Oxford University Press, Inc., Oxford, UK.

[29] Reips, U.D., and Funke, F. (2008). Interval-level measurement with visual analogue scales in internet-based research: VAS Generator. Behav Res Methods, 40(3), 699-704.

[30] Grant, S., Aitchison, T., Henderson, E., Christie, J., Zare, S., McMurray, J., and Dargie, H. (1999). A comparison of the reproducibility and the sensitivity to change of visual analogue scales, Borg scales, and Likert scales in normal subjects during submaximal exercise. Chest, 116(5), 1208-1217.

[31] Powell, R.A., Downing, J., Ddungu, H., and Mwangi-Powell, F.N. (2010). Guide to Pain Management in Low-Resource Settings. Seattle, WA: IASP.

[32] Young, I.A., Cleland, J.A., Michener, L.A., and Brown, C. (2010). Reliability, construct validity, and responsiveness of the Neck Disability Index, Patient-Specific Functional Scale, and Numeric Pain Rating Scale in patients with cervical radiculopathy. Am J Phys Med Rehabil, 89(10), 831-839. doi: 10.1097/PHM.0b013e3181ec98e6.

[33] Cleland, J.A., Childs, J.D., and Whitman, J.M. (2008). Psychometric properties of the Neck Disability Index and Numeric Pain Rating Scale in patients with mechanical neck pain. Arch Phys Med Rehabil, 89(1), 69-74. doi: 10.1016/j.apmr.2007.08.126.

[34] McCaffery, M., and Pasero, C. (1999). Pain: Clinical Manual. St. Louis, MO: Mosby, Inc.

[35] Williamson, A., and Hoggart, B. (2005). Pain: A review of three commonly used pain rating scales. J Clin Nurs, 14(7), 798-804. doi: 10.1111/j.1365-2702.2005.01121.x.

[36] Wong, D.L., Hackenberry-Eaton, M., Wilson, D., Winkelstein, M.L., and Swchwartz, P. (2001). Wong's Essentials of Pediatric Nursing. St. Louis, MO: Mosby, Inc.

[37] Melzack, R. (1975). The McGill Pain Questionnaire: Major properties and scoring methods. Pain, 1(3), 277-299.

[38] Kerns, R.D., Turk, D.C., and Rudy, T.E. (1985). The West Haven-Yale Multidimensional Pain Inventory (WHYMPI). Pain, 23(4), 345-356.

[39] MacDermid, J.C., Walton, D.M., Avery, S., Blanchard, A., Etruw, E., McAlpine, C., and Goldsmith, C.H. (2009). Measurement properties of the Neck Disability Index: A systematic review. J Orthop Sports Phys Ther, 39(5), 400-417. doi: 10.2519/jospt.2009.2930.

[40] Vernon, H., and Mior, S. (1991). The Neck Disability Index: A study of reliability and validity. J Manipulative Physiol Ther, 14(7), 409-415.

[41] Young, B.A., Walker, M.J., Strunce, J.B., Boyles, R.E., Whitman, J.M., and Childs, J.D. (2009). Responsiveness of the Neck Disability Index in patients with mechanical neck disorders. Spine J, 9(10), 802-808. doi: 10.1016/j.spinee.2009.06.002.

[42] Misailidou, V., Malliou, P., Beneka, A., Karagiannidis, A., and Godolias, G. (2010). Assessment of patients with neck pain: A review of definitions, selection criteria, and measurement tools. J Chiropr Med, 9(2), 49-59. doi: 10.1016/j.jcm.2010.03.002.

[43] Smith, A.M. (2016). The prevalence and operational significance of neck pain and back pain in Air Combat Group: IAM-2016-003-CR, Institute of Aviation Medicine – Adelaide, Adelaide, Australia.

[44] Walton, D.M., and MacDermid, J.C. (2013). A brief 5-item version of the Neck Disability Index shows good psychometric properties. Health Qual Life Outcomes, 11, 108. doi: 10.1186/1477-7525-11-108.

[45] Beurskens, A.J., Bultmann, U., Kant, I., Vercoulen, J.H., Bleijenberg, G., and Swaen, G.M. (2000). Fatigue among working people: Validity of a questionnaire measure. Occup Environ Med, 57(5), 353-357.

[46] Vercoulen, J., Alberts, M., and Bleijenberg, G. (1999). De Checklist Individual Strength. Gedragstherapie, 32, 131-136.

[47] Chalder, T., Berelowitz, G., Pawlikowska, T., Watts, L., Wessely, S., Wright, D., and Wallace, E.P. (1993). Development of a fatigue scale. J Psychosom Res, 37(2), 147-153.

[48] Michielsen, H.J., De Vries, J., and Van Heck, G.L. (2003). Psychometric qualities of a brief self-rated fatigue measure: The Fatigue Assessment Scale. J Psychosom Res, 54(4), 345-352.

[49] Maslach, C., and Jackson, S. (1986). Manual, 2nd edition, Palo Alto, CA: Sage.

[50] WHOQOL. (1998). World Health Organization Quality of Life (WHOQOL) Group: Development of the World Health Organization WHOQOL-BREF Quality of Life Assessment. Psychol Med, 28(3), 551-558.

[51] Borg, G.A. (1982). Psychophysical bases of perceived exertion. Med Sci Sports Exerc, 14(5), 377-381.

[52] Pellettiere, J.A., Parakkat, J., Reynolds, D., Sasidharan, M., and El-Zoghbi, M. (2005). Quantitative methods for determining U.S. Air Force crew cushion comfort. In: A.F.R. Laboratory (Ed.), AFRL-HE-WP-TP-2005-0021, Wright-Patterson Air Force Base, Dayton, OH.

[53] Smith, D.R., Andrews, D.M., and Wawrow, P.T. (2006). Development and evaluation of the Automotive Seating Discomfort Questionnaire (ASDQ). International Journal of Industrial Ergonomics, 36, 141-149.

[54] Corlett, E.N., and Bishop, R.P. (1976). A technique for assessing postural discomfort. Ergonomics, 19(2), 175-182. doi: 10.1080/00140137608931530.

[55] Hamberg-van Reenen, H.H., van der Beek, A.J., Blatter, B.M., van der Grinten, M.P., van Mechelen, W., and Bongers, P.M. (2008). Does musculoskeletal discomfort at work predict future musculoskeletal pain? Ergonomics, 51(5), 637-648.

[56] Miller, R.P., Kori, S., and Todd, D. (1991). The Tampa Scale: A measure of kinesiophobia. Clinical Journal of Pain, 7(1), 51-52.

[57] Snaith, R.P. (2003). The Hospital Anxiety and Depression Scale. Health Qual Life Outcomes, 1, 29. doi: 10.1186/1477-7525-1-29.

[58] Main, C.J., Wood, P.L., Hollis, S., Spanswick, C.C., and Waddell, G. (1992). The Distress and Risk Assessment Method: A simple patient classification to identify distress and evaluate the risk of poor outcome. Spine (Philadelphia, PA, 1976), 17(1), 42-52.

[59] Kroenke, K., Spitzer, R.L., and Williams, J.B. (2002). The PHQ-15: Validity of a new measure for evaluating the severity of somatic symptoms. Psychosom Med, 64(2), 258-266.

[60] Szalma, J.L., Warm, J.S., Matthews, G., Dember, W.N., Weiler, E.M., Meier, A., and Eggemeier, F.T. (2004). Effects of sensory modality and task duration on performance, workload, and stress in sustained attention. Hum Factors, 46(2), 219-233.

[61] Picavet, H.S., Vlaeyen, J.W., and Schouten, J.S. (2002). Pain catastrophizing and kinesiophobia: predictors of chronic low back pain. Am J Epidemiol, 156(11), 1028-1034.

[62] Sullivan, H.J.L., Bishop, S.R., and Pivik, J. (1995). The Pain Catastrophizing Scale: Development and validation. Psychological Assessment, 7, 524-532.

[63] Marhold, C., Linton, S.J., and Melin, L. (2002). Identification of obstacles for chronic pain patients to return to work: Evaluation of a questionnaire. J Occup Rehabil, 12(2), 65-75.

[64] Baecke, J.A., Burema, J., and Frijters, J.E. (1982). A short questionnaire for the measurement of habitual physical activity in epidemiological studies. Am J Clin Nutr, 36(5), 936-942.

[65] Hart, S.G., and Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: P.A. Hancock and N. Meshkati (Eds.), Human Mental Workload. Amsterdam, the Netheralnds: North Holland Press.

[66] Rehmann, A.J. (1995). Handbook of human performance measures and crew requirements for flightdeck research. In: F.A. Administration (Ed.), DOT/FAA/CT-TN95-49, U.S. Department of Transportation, Atlantic City Airport, NJ.

[67] Roscoe, A.H., and Ellis, G.A. (1990). A subjective rating scale for assessing pilot workload in flight: A decade of practical use: Technical Report TR 90019, Royal Aerospace Establishment, Ministry of Defence, Farnborough, Hampshire, UK.

[68] Wainwright, W.A. (1987). Flight test evaluation of crew workload. In: A.H. Roscoe (Ed.), The Practical Assessment of Pilot Workload, AGARD No 282. Paris, France.

[69] Carton, R.L., and Rhodes, E.C. (1985). A critical review of the literature on ratings scales for perceived exertion. Sports Med, 2(3), 198-222. doi: 10.2165/00007256-198502030-00004.

[70] Aday, L.A., and Cornelius, L.J. (2006). Designing and conducting health surveys: A comprehensive guide. San Francisco, CA: John Wiley and Sons, Inc.

[71] Blair, J., Czaja, R.F., and Blair, E.A. (2013). Designing surveys: A guide to decisions and procedures. Los Angeles, CA: SAGE Publications, Inc.

[72] Boynton, P.M., and Greenhalgh, T. (2004). Selecting, designing, and developing your questionnaire. BMJ, 328(7451), 1312-1315. doi: 10.1136/bmj.328.7451.1312.

[73] Fink, A. (2012). How to conduct surveys: A step-by-step guide. Los Angeles, CA: SAGE Publications, Inc.

[74] Gillham, B. (2008). Developing a questionnaire. London, UK: Continuum International Publishing Group.

[75] McDowell, I. (2006). Measuring health: A guide to rating scales and questionnaires. New York, NY: Oxford University Press.

[76] Coughlin, S.S. (1990). Recall bias in epidemiologic studies. J Clin Epidemiol, 43(1), 87-91.

[77] Hassan, E. (2006). Recall bias can be a threat to retrospective and prospective research designs. The Internet Journal of Epidemiology, 3(2), 339-412.

[78] Gabbe, B.J., Finch, C.F., Bennell, K.L., and Wajswelner, H. (2003). How valid is a self-reported 12-month sports injury history? Br J Sports Med, 37(6), 545-547.

[79] Kjellsson, G., Clarke, P., and Gerdtham, U.G. (2014). Forgetting to remember or remembering to forget: A study of the recall period length in health care survey questions. J Health Econ, 35, 34-46. doi: 10.1016/j.jhealeco.2014.01.007.

[80] Hill, A.B. (1965). The environment and disease: Association or causation? Proc R Soc Med, 58, 295-300.

[81] Chafé, G.S., and Farrell, P.S.E. (2016). Royal Canadian Air Force CH-146 Griffon aircrew 2014 spinal musculoskeletal trouble survey. Toronto, Canada: Scientific Report, DRDC-RDDC-2016-R179, Defence Research and Development Canada, Toronto, Canada.

[82] Duvigneaud, N., Emonds, D., Bagaianu, D., van den Oord, M., and Van Tiggelen, D. (2016). Neck and back pain among BAF F-16 pilots. Paper presented at the Ramstein Aerospace Medicine Summit, Ramstein, Germany.

[83] Smith, E.E. (2017). Neck pain in RCAF fast jet pilots. Paper presented at the RAMS/USAF and NATO STO Technical Course, Ramstein, Germany.

[84] Duvigneaud, N., and Van Rompay, A. (2018). Survey of neck and back pain in ODF pilots. Paper presented at the RAMS/USAF and NATO STO Technical Course, Ramstein, Germany.

[85] De Loose, V., Burnotte, F., Cagnie, B., Stevens, V., and Van Tiggelen, D. (2008). Prevalence and risk factors of neck pain in military office workers. Mil Med, 173(5), 474-479.

[86] Smith, A.M. (2018a). Accuracy of flying experience estimated by aircrew. Paper presented at the Aerospace Medical Association, Dallas, TX.

[87] Smith, A.M. (2018b). Accuracy of flying experience estimated by aircrew: IAM-2018-004-TR, RAAF Institute of Aviation Medicine, Adelaide, Australia.

[88] Ashwell, M., Gunn, P., and Gibson, S. (2012). Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: Systematic review and meta-analysis. Obes Rev, 13(3), 275-286. doi: 10.1111/j.1467-789X.2011.00952.x.

[89] Cote, P., van der Velde, G., Cassidy, J.D., Carroll, L.J., Hogg-Johnson, S., Holm, L.W., et al. (2008). The burden and determinants of neck pain in workers: Results of the Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders. Spine (Philadelphia, PA, 1976), 33(4 Suppl), S60-74. doi: 10.1097/BRS.0b013e3181643ee4.

[90] de Koning, C.H., van den Heuvel, S.P., Staal, J.B., Smits-Engelsman, B.C., and Hendriks, E.J. (2008). Clinimetric evaluation of active range of motion measures in patients with non-specific neck pain: A systematic review. Eur Spine J, 17(7), 905-921. doi: 10.1007/s00586-008-0656-3.

[91] Williams, M.A., Williamson, E., Gates, S., and Cooke, M.W. (2012). Reproducibility of the cervical range of motion (CROM) device for individuals with sub-acute whiplash associated disorders. Eur Spine J, 21(5), 872-878. doi: 10.1007/s00586-011-2096-8.

[92] Ang, B., Linder, J., and Harms-Ringdahl, K. (2005). Neck strength and myoelectric fatigue in fighter and helicopter pilots with a history of neck pain. Aviat Space Environ Med, 76(4), 375-380.

[93] Smith, C.A., Chimera, N.J., Wright, N.J., and Warren, M. (2013). Interrater and intrarater reliability of the functional movement screen. J Strength Cond Res, 27(4), 982-987. doi: 10.1519/JSC.0b013e3182606df2.

[94] Teyhen, D., Bergeron, M.F., Deuster, P., Baumgartner, N., Beutler, A.I., de la Motte, S.J., … O'Connor, F. (2014). Consortium for health and military performance and American College of Sports Medicine Summit: Utility of functional movement assessment in identifying musculoskeletal injury risk. Curr Sports Med Rep, 13(1), 52-63. doi: 10.1249/JSR.0000000000000023.

[95] Zagatto, A.M., Beck, W.R., and Gobatto, C.A. (2009). Validity of the running anaerobic sprint test for assessing anaerobic power and predicting short-distance performances. J Strength Cond Res, 23(6), 1820-1827. doi: 10.1519/JSC.0b013e3181b3df32.

[96] Keir, D.A., Theriault, F., and Serresse, O. (2013). Evaluation of the running-based anaerobic sprint test as a measure of repeated sprint ability in collegiate-level soccer players. J Strength Cond Res, 27(6), 1671-1678. doi: 10.1519/JSC.0b013e31827367ba.

[97] Bateman, W.A., Jacobs, I., and Buick, F. (2006). Physical conditioning to enhance +Gz tolerance: Issues and current understanding. Aviat Space Environ Med, 77(6), 573-580.

[98] Borillo, D.J. (1999). Back pain in helicopter pilots. Aviat Space Environ Med, 70, 533-534.

[99] Grossman, A., Nakdimon, I., Chapnik, L., and Levy, Y. (2012). Back symptoms in aviators flying different aircraft. Aviat Space Environ Med, 83(7), 702-705.

[100] Lange, B., Nielsen, R.T., Skejo, P.B., and Toft, P. (2013). Centrifuge-induced neck and back pain in F-16 pilots: A report of four cases. Aviat Space Environ Med, 84(7), 734-738.

[101] Landau, D.A., Chapnick, L., Yoffe, N., Azaria, B., Goldstein, L., and Atar, E. (2006). Cervical and lumbar MRI findings in aviators as a function of aircraft type. Aviat Space Environ Med, 77(11), 1158-1161.

[102] Sovelius, R., Salonen, O., Lamminen, A., Huhtala, H., and Hamalainen, O. (2008). Spinal MRI in fighter pilots and controls: A 13-year longitudinal study. Aviat Space Environ Med, 79(7), 685-688.

[103] Shiri, R., Frilander, H., Sainio, M., Karvala, K., Sovelius, R., Vehmas, T., and Viikari-Juntura, E. (2015). Cervical and lumbar pain and radiological degeneration among fighter pilots: A systematic review and meta-analysis. Occup Environ Med, 72(2), 145-150. doi: 10.1136/oemed-2014-102268.

[104] Burns, J.W., Loecker, T.H., Fischer, J.R., Jr., and Bauer, D.H. (1996). Prevalence and significance of spinal disc abnormalities in an asymptomatic acceleration subject panel. Aviat Space Environ Med, 67(9), 849-853.

[105] Ahmad, S., Tejuja, A., Newman, K.D., Zarychanski, R., and Seely, A.J. (2009). Clinical review: A review and analysis of heart rate variability and the diagnosis and prognosis of infection. Crit Care, 13(6), 232. doi: 10.1186/cc8132.

[106] Flouris, A.D., Bravi, A., Wright-Beatty, H.E., Green, G., Seely, A.J., and Kenny, G.P. (2014). Heart rate variability during exertional heat stress: Effects of heat production and treatment. Eur J Appl Physiol, 114(4), 785-792. doi: 10.1007/s00421-013-2804-7.

[107] Tousignant-Laflamme, Y., Rainville, P., and Marchand, S. (2005). Establishing a link between heart rate and pain in healthy subjects: A gender effect. J Pain, 6(6), 341-347. doi: 10.1016/j.jpain.2005.01.351.

[108] Shaffer, F., and Ginsberg, J.P. (2017). An overview of heart rate variability metrics and norms. Front Public Health, 5, 258. doi: 10.3389/fpubh.2017.00258.

[109] Terkelsen, A.J., Molgaard, H., Hansen, J., Andersen, O.K., and Jensen, T.S. (2005). Acute pain increases heart rate: Differential mechanisms during rest and mental stress. Auton Neurosci, 121(1-2), 101-109. doi: 10.1016/j.autneu.2005.07.001.

[110] Appelhans, B.M., and Luecken, L.J. (2008). Heart rate variability and pain: Associations of two interrelated homeostatic processes. Biol Psychol, 77(2), 174-182. doi: 10.1016/j.biopsycho.2007.10.004.

[111] Hallman, D.M., Olsson, E.M., von Scheele, B., Melin, L., and Lyskov, E. (2011). Effects of heart rate variability biofeedback in subjects with stress-related chronic neck pain: A pilot study. Appl Psychophysiol Biofeedback, 36(2), 71-80. doi: 10.1007/s10484-011-9147-0.

[112] Sacco, M., Meschi, M., Regolisti, G., Detrenis, S., Bianchi, L., Bertorelli, M., … Caiazza, A. (2013). The relationship between blood pressure and pain. J Clin Hypertens (Greenwich), 15(8), 600-605. doi: 10.1111/jch.12145.

[113] Tennant, F. (2013). The physiologic effects of pain on the endocrine system. Pain Ther, 2(2), 75-86. doi: 10.1007/s40122-013-0015-x.

[114] Bruehl, S., Chung, O.Y., Jirjis, J.N., and Biridepalli, S. (2005). Prevalence of clinical hypertension in patients with chronic pain compared to non-pain general medical patients. Clin J Pain, 21(2), 147-153.

[115] Braun, S.R. (1990). Clinical Methods: The History, Physical, and Laboratory Examinations, 3rd ed., Boston, MA: Butterworths.

[116] Fowles, D.C., Christie, M.J., Edelberg, R., Grings, W.W., Lykken, D.T., and Venables, P.H. (1981). Committee report. Publication recommendations for electrodermal measurements. Psychophysiology, 18(3), 232-239.

[117] Ledowski, T., Bromilow, J., Wu, J., Paech, M.J., Storm, H., and Schug, S.A. (2007). The assessment of postoperative pain by monitoring skin conductance: Results of a prospective study. Anaesthesia, 62(10), 989-993. doi: 10.1111/j.1365-2044.2007.05191.x.

[118] Storm, H. (2008). Changes in skin conductance as a tool to monitor nociceptive stimulation and pain. Curr Opin Anaesthesiol, 21(6), 796-804. doi: 10.1097/ACO.0b013e3283183fe4.

[119] Ballantyne, C.M., and Nambi, V. (2005). Markers of inflammation and their clinical significance. Atheroscler Suppl, 6(2), 21-29. doi: 10.1016/j.atherosclerosissup.2005.02.005.

[120] Brenner, D.R., Scherer, D., Muir, K., Schildkraut, J., Boffetta, P., Spitz, M.R., … Hung, R.J. (2014). A review of the application of inflammatory biomarkers in epidemiologic cancer research. Cancer Epidemiol Biomarkers Prev, 23(9), 1729-1751. doi: 10.1158/1055-9965.EPI-14-0064.

[121] DeVon, H.A., Piano, M.R., Rosenfeld, A.G., and Hoppensteadt, D.A. (2014). The association of pain with protein inflammatory biomarkers: A review of the literature. Nurs Res, 63(1), 51-62. doi: 10.1097/NNR.0000000000000013.

[122] Wright, H.E., Selkirk, G.A., and McLellan, T.M. (2010). HPA and SAS responses to increasing core temperature during uncompensable exertional heat stress in trained and untrained males. Eur J Appl Physiol, 108(5), 987-997.

[123] Marchi, A., Vellucci, R., Mameli, S., Rita Piredda, A., and Finco, G. (2009). Pain biomarkers. Clin Drug Investig, 29 Suppl 1, 41-46. doi: 10.2165/0044011-200929001-00006.

[124] Schell, E., Theorell, T., Hasson, D., Arnetz, B., and Saraste, H. (2008). Stress biomarkers' associations to pain in the neck, shoulder and back in healthy media workers: 12-month prospective follow-up. Eur Spine J, 17(3), 393-405. doi: 10.1007/s00586-007-0554-0.

[125] Cifrek, M., Medved, V., Tonkovic, S., and Ostojic, S. (2009). Surface EMG-based muscle fatigue evaluation in biomechanics. Clin Biomech (Bristol, Avon), 24(4), 327-340. doi: 10.1016/j.clinbiomech.2009.01.010.

[126] Clancy, E.A., Morin, E.L., and Merletti, R. (2002). Sampling, noise-reduction and amplitude estimation issues in surface electromyography. J Electromyogr Kinesiol, 12(1), 1-16.

[127] Law, A., Wright Beatty, H.E., Karakolis, T., and Farrell, P. (2018). Electromyography signal processing and amplitude normalization. (LTR-FRL-2018-0049). Ottawa, Canada: National Research Council.

[128] Potvin, J.R., and Brown, S.H. (2004). Less is more: High pass filtering, to remove up to 99% of the surface EMG signal power, improves EMG-based biceps brachii muscle force estimates. J Electromyogr Kinesiol, 14(3), 389-399. doi: 10.1016/j.jelekin.2003.10.005.

[129] Wright Beatty, H.E., Law, A., Thomas, J.R., and Wickramasinghe, V. (2018). Amplified pilot head acceleration and neck muscle strain: Effective vibration mitigation. Aerospace Medicine and Human Performance, 89(6), 1-10.

[130] Konrad, P. (2005). The ABC of EMG: A practical introduction to kinesiological electromyography. USA: Noraxon Inc.

[131] De Luca, C.J. (1997). The use of surface electromyography in biomechanics. Journal of Applied Biomechanics, 13(2), 135-163.

[132] De Luca, C.J., Gilmore, L.D., Kuznetsov, M., and Roy, S.H. (2010). Filtering the surface EMG signal: Movement artifact and baseline noise contamination. J Biomech, 43(8), 1573-1579. doi: 10.1016/j.jbiomech.2010.01.027.

[133] Merletti, R., and di Torino, P. (1999). Standards for reporting EMG data. Journal of Electromyography and Kinesiology, 9(1), 3-4.

[134] Hedayatpour, N., and Falla, D. (2015). Physiological and neural adaptations to eccentric exercise: Mechanisms and considerations for training. Biomed Res Int, 2015, 193741. doi: 10.1155/2015/193741.

[135] Hedayatpour, N., Falla, D., Arendt-Nielsen, L., and Farina, D. (2010). Effect of delayed-onset muscle soreness on muscle recovery after a fatiguing isometric contraction. Scand J Med Sci Sports, 20(1), 145-153. doi: 10.1111/j.1600-0838.2008.00866.x.

[136] Prasartwuth, O., Taylor, J.L., and Gandevia, S.C. (2005). Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles. J Physiol, 567(Pt 1), 337-348. doi: 10.1113/jphysiol.2005.087767.

[137] Vila-Cha, C., Hassanlouei, H., Farina, D., and Falla, D. (2012). Eccentric exercise and delayed onset muscle soreness of the quadriceps induce adjustments in agonist-antagonist activity, which are dependent on the motor task. Exp Brain Res, 216(3), 385-395. doi: 10.1007/s00221-011-2942-2.

Chapter 4 – NECK PAIN PREVENTION AND MANAGEMENT – HUMAN FACTORS

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4.0 SUMMARY

When discussing neck pain, it is useful to view musculoskeletal injury as being on a spectrum spanning fully healthy to permanently disabled. It is hypothesised that in non-collision injuries, there are lag periods between dysfunction occurring, said dysfunction being measurable, and finally the aircrew perceiving a physical problem or injury (see Figure 4-1). This perspective helps to explain why in most (if not all) health conditions, early intervention is the most cost-effective course of action in terms of aircrew health, treatment outcomes, and operational effectiveness. In this chapter, we consider aircrew wellness status as a continuum from fully healthy through to permanently disabled. We review the human-related aspects (i.e., Human factors) of prevention (Section 4.1), education (Section 4.2), exercise studies (Section 4.3), work-rest cycles (Section 4.4), and

treatment (Section 4.5) methods to overcome fatigue, strain and injury, explore approaches to treat acute and chronic pain, and end with a discussion of aeromedical disposition (Section 4.6).

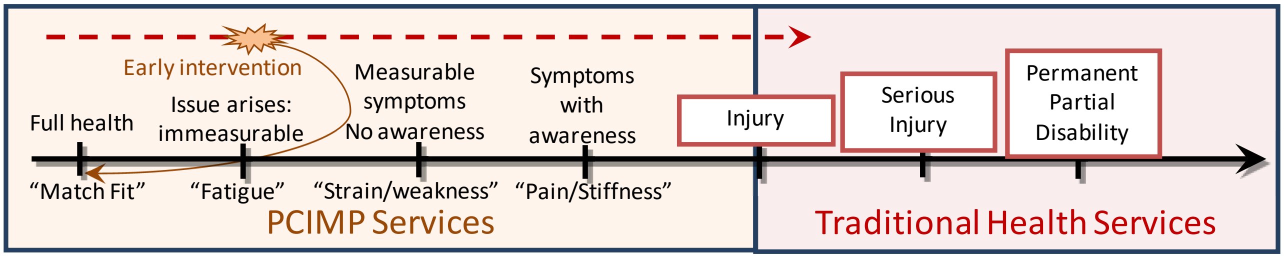

Figure 4-1: Aircrew Wellness Status as a Continuum. (PCIMP: Physical Conditioning and Injury Mitigation Programme). Adapted from the Royal Australian Air Force.

4.1 PREVENTION/INTERVENTION OVERVIEW

Injury prevention can be divided into three categories (as per the pathology-based categorisation of prevention) [1], [2]:

- **Primary prevention:** aims to prevent injury through removal or reduction of its possible causative factors (i.e., prior to injury occurring). Aircrew education, targeted physical conditioning, baseline screening, and post-flight briefing have the potential to remove or reduce the possible causative factors, including neck fatigue and strain.
- **Secondary prevention:** aims to detect injury at a point early enough in its development where intervention can prevent its progression or worsening (i.e., once they are injured, and potentially before they are symptomatic). Baseline screening, ongoing regular monitoring, post-flight briefing, regular Physiotherapy review, and targeted rehabilitation (including early referral to Physiotherapy/Medical) can all be considered to have 'secondary' prevention components due to their role in identifying injuries in their early stages.
- **Tertiary prevention:** aims to reduce complications and any long-term burden associated with an injury (i.e., once they have an established injury). Regular Physiotherapy review and targeted rehabilitation can be considered to have 'tertiary' prevention components due to their role in minimising the impact of injury upon flying, minimising the time required to return to flying, and minimising the risks for subsequent injury.

Treatment on the neck injury spectrum encourages timely intervention and options vary depending on injury severity, tissue type and persistence of the pain.

4.2 EDUCATION PROGRAMS

4.2.1 Summary of National Education Programs

Education combined with some practical application of what is learned will help aircrew acquire or maintain knowledge and skills to manage the risks of neck pain during their career. This section summarises common education practices of different nations. Some parts specifically aim to prevent neck pain, while other parts aim to educate aircrew to adopt a healthy lifestyle and behaviours that will support good musculoskeletal health. It is critical to develop good habits early in an aviator's career that will reduce the risk of tissue damage and emphasise beneficial habits during refresher training. While it is beyond the scope of the report to describe the content of each nation's education programs in detail, a summary is provided in Table 4-1. See Annex F for more details.

Table 4-1: Summary of Common Education Practices.

Action Items Performed in Different Nations	AUS	BEL	CAN	FIN	GER	ITA	NLD	NOR	POR	UK	US Army	USAF	USN
Academics (see Section 4.2.2.2): Lessons to Improve Aircrew Knowledge													
Anatomy of spine	✓	✓	✓	✓		✓	✓			✓		✓	✓
Cockpit ergonomics	✓	✓	✓	✓	✓		✓		✓	✓		✓	✓
Contributing factors +	✓	✓	✓	✓	✓		✓		✓	✓			✓
Gz load and loading	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Neurology							✓						
Nutrition		✓	✓	✓	✓	✓		✓	✓	✓		✓	
Preventive exercises	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Recovery methods	✓	✓	✓	✓	✓	✓				✓			✓
Work-rest cycle	✓	✓	✓	✓					✓		✓	✓	✓
Handout or guidebook provided	✓	✓	✓							✓	✓		
Physical Training Programs													
General training programs for aircrew	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Neck-specific training programmes for aircrew	✓	✓	✓	✓	✓	✓	✓			✓			
Individually targeted general training programs	✓		✓		✓		✓			✓			
Individually targeted neck-specific training programmes	✓	✓	✓	✓	✓		✓			✓			
Specific sports camps for aircrew				✓	✓								
Other Practical Solutions													
Cockpit ergonomics training	✓		✓	✓			✓			✓			✓
Controlled helmet fitting			✓		✓		✓		✓		✓		

Action Items Performed in Different Nations	AUS	BEL	CAN	FIN	GER	ITA	NLD	NOR	POR	UK	US Army	USAF	USN
Lumbar supports			✓	✓			✓		✓	✓		✓	✓
Other equipment or gear			✓					✓			✓		✓

+ These include posture, head movements, cockpit ergonomics, flight equipment (head-worn mass), proper equipment fit, flight duration, G forces, whole-body vibrations, unexpected movements, and individual factors (anthropometrics).

Nation Notes:

AUS: Work-Rest Cycle, anatomy of the spine, contributing factors, individually targeted training, individually targeted neck-specific training, cockpit ergonomics training.

BEL: Briefing about healthy/sports nutrition has been given since Nov 2016 to student pilots. General and specific neck training is mandatory for student but optional for operational pilots. Cockpit ergonomics is discussed as a contributing factor.

CAN: Updated its education programme in 2018 and expanded education in cockpit ergonomics, nutrition, contributing factors, and neck training is in development for a 2019 start.

GER: Anthropometric data are collected every three years at GER Institute during the examination (annually from the age of 40).

NLD: At this moment there is a workgroup investigating the content and possibilities of implementation of a specific neck/back training programme, and whether it has to be individually tailored. Not implemented yet. There is also no specific aircrew physical education training, but cockpit ergonomics in the academics part includes cockpit strategies (in-flight movements, in-flight exercises, etc.). Some aircrew fly with an individual tailored lumbar support/cushion and NLD is working on getting this formalised and certified.

UK: Aircrew Conditioning Programme is delivered to all aircrew (rotary and fast jet) during all stages of flying training. Cockpit ergonomics training is being considered for Typhoon. UK currently uses individually moulded lumbar supports but is looking at using off-the-shelf models.

USAF: Lumbar supports are only approved for certain aircraft.

USN: Flight surgeon brief contains information on other equipment but not necessarily translated to support personnel.

4.2.2 General Requirements for Education Programmes

4.2.2.1 Motivation

While the aeromedical and engineering community can provide technological mitigations and recommend procedures for reducing risk and magnitude of spinal pain, it is ultimately incumbent on aircrew to adopt a healthy lifestyle and behaviours that will support good musculoskeletal health. Some things are relatively simple to implement, such as an awareness of posture and movement. For example, if the restraint harness and inertia locking mechanism allows, in order to look over the shoulder (“check-6”), if a pilot rotates their shoulders to move the neck and head as a unit rather than simply rotating the neck, the load and stress on the neck is greatly reduced. What is critical is to develop good habits early in an aviator's career that will reduce the risk of tissue damage and emphasize beneficial habits during refresher training. The following section summarizes multinational "best of practice" advice based upon the views and expert opinions of RTG members currently involved in studying and implementing education programmes in their nations.

4.2.2.2 Academic and Practical Components

It is important to provide not just the academic foundations to aircrew to promote good spinal health but to discuss the associated practical components in order to be effective [3].

1) **Anatomy of the spine** refers to the basic structure and function of the spine, including range of motion limits and the importance of the shape of the spine in neutral position (lordosis-kyphosis-lordosis). It is important for aircrew to appreciate basic anatomy, so they understand their physical limits and do not injure themselves by pushing beyond those limits.

   a) Aircrew are taught about proper posture and the effects on the spine of adopting different postures. This includes effects on the facet joints, stabilizing muscles, and how the capacity of the spine decreases as it moves further from the neutral position.

   b) Aircrew are also educated about compensatory strategies they can use in flight to minimise the effects of different postures that must be adopted in flight. For example, by teaching the aircrew that by moving their upper body with their neck when looking in a particular direction (e.g., check six), their neck is better supported by the shoulder, the neck angle will be less extreme and consequently the stress on the neck is less.

   c) Aircrew are also taught about the neurological structures in the spine (spinal cord and spinal nerves) and their function, how they can be irritated or injured, and how to recognise the signs and symptoms of such. When aircrew understand more about what pain is and how it works, it can reduce the "threat value" of pain and therefore can help reduce pain itself.

2) **Cockpit ergonomics** refers to the body position in relation to the controls and the interaction between the two. Most seats allow horizontal front-back and vertical up down adjustment. Some aircraft also have adjustable rudder pedals and armrests.

   a) The cockpit design includes: the configuration of the seat itself and any possible adjustments that can be made; the aircrew anthropometric limitations; aircrew position and posture in flight; and how tasks are performed by aircrew. The individual aircrew should adjust the seat setting for optimal field of view, function and comfort for flying the mission. Aircrew are taught that they also should consider their posture when adjusting the seat position; for example, a hip angle less than 90° will increase the risk of spinal pain as this will cause excessive forward translation and flexion in the neck.

   b) In addition to seat position, aircrew are taught to avoid body positions during certain tasks which may contribute to neck pain/injury and will also ensure that they are within the anthropometric limits of the aircraft. If minor modifications are required (and permitted) or additional devices required (such as lumbar support devices), then this can be identified during these assessments as well. (Lumbar supports refer to use of a device placed in the lumbar region if approved for flight [4].)

3) **Contributing factors** refer .to how in-flight factors can contribute to, can interact, and be additive, raising the potential for pain and injury. For neck pain/injury, these can be divided into flight-related and non-flight-related factors.

a) Flight-related factors include (but are not limited to) posture, head movements, cockpit ergonomics, flight equipment, helmet fit, flight duration, G forces, whole-body vibrations, unexpected movements, individual factors, etc. The mechanisms by which these factors contribute to neck pain are discussed in greater detail elsewhere. With respect to education, the intent is to teach aircrew that these factors exist so that they are more aware of them and can minimise the risk when able. For example, if aircrew understand that CoM of Head-Supported Mass (HSM) affects their risk of neck pain/injury, they will be more cognizant of how much counterweight they use and remove NVGs when not in use.

b) Recall from Chapter 2 that non-flight-related risk factors include age, previous musculoskeletal pain, high job demands, low occupational social support, job insecurity, low physical capacity, poor computer workstation ergonomic design and associated work posture, sedentary work position, repetitive work, and precision work [5]. Depending on the aircraft/community, military aircrew will average 50 – 400 flying hours per year. This leaves approximately 8,310 – 8,710 hours a year that they spend doing other things. Aircrew are taught how non-flying factors can contribute to neck pain, either directly (e.g., contact sports) or indirectly (e.g., poor sleep, which makes them vulnerable to injury). The importance of good ergonomics in the workplace and home and how this can contribute to neck pain/injury is also taught (e.g., position of computer monitor and keyboard relative to the arms and chair height).

c) *Proper equipment fit* refers to education of aircrew and the technicians responsible for Aviation Life Support Equipment (ALSE) regarding the ALSE worn in flight, how it is intended to fit, the importance of wearing it properly and ensuring the continued integrity of proper fit throughout their careers. ALSE typically includes (but is not limited to): helmet (which may also include monocular or binocular NVGs and/or a special helmet-mounted display), survival vest, harness, and G-suit. Billions of dollars are spent on research, development, procurement and maintenance of ALSE. However, if this equipment is not fitted properly, worn properly and maintained properly, injuries will occur regardless, and all the time and resources spent developing and procuring it are for naught.

i) Many aircrews are fit for this equipment early in their careers when they have very little experience and do not return for re-fitting until there is a significant problem. Many have not worn this equipment before at the time of the initial fit so cannot differentiate between equipment that is fit properly or not, unless/until there are significant problems. However, if additional mandatory fittings at various points in each individual's career occur (especially during training), this will ensure that as they gain more flight time/experience, there is an opportunity to adjust the ALSE as necessary to ensure continued proper fit. For example, in most countries, all student pilots undergo an initial fit early in their flight training but are not required to return for a follow-up assessment with ALSE Technicians unless they experience problems. By including additional ALSE follow-up fittings into the training syllabus (e.g., after 5, 20, 50 flights), aircrew will have the opportunity to make adjustments to their ALSE as required without needing to 'make time' to return to ALSE. The intent of including this information into the syllabus is to enable aircrew to recognise ill-fitting ALSE early and be proactive in rectifying this before it can contribute to neck pain/injury.

ii) ALSE technicians work in a niche environment. Some countries have gone to great lengths to develop and implement extensive equipment fitting processes to ensure proper fit and reduce the risk of injury due to ill-fitting ALSE. For example, the Netherlands have developed a helmet fit process (outlined in Section 5.3.1 of this report) which, as a result of this collaborative research task group, has now been adopted by some of the other participating allied nations' forces. As equipment changes and new techniques are developed, it is important to also update education and training curriculum for the technicians who maintain ALSE and conduct fittings. For example, a group of senior ALSE technicians at the Canadian Forces Environmental Medicine Establishment (CFEME) in Toronto developed a training package to introduce proper helmet fitting technique to technicians currently employed in RCAF units. The CFEME ALSE team travelled across the country delivering this training to all RCAF units, who are now also able to fit helmets using the new process.

4) **Gz load and loading** refer to learning about the additional gravitational forces (Gs) generated while flying. Usually the largest additional Gs are along the "Head to Foot" axis known as Gz. In controlled flight, the largest loads are usually encountered when pulling back on the stick while turning, shifting the blood from the head toward the feet. Nomenclature refers to this as the +Gz vector. Some current fighter aircraft can generate up to +9 Gz. See Section 4.2.2.2.1 for additional details.

   a) As +Gz increases, the resultant forces on the structures in the neck also increase. Aircrew are taught various strategies to minimise the impact of +Gz forces on their neck during flight. These include: pre-position the head before the onset of +Gz; minimise head movements during exposure to +Gz; and, wait to move the head again until offloading +Gz, when possible.

   b) A number of factors dependent and independent of head-supported mass can increase the risk of neck pain in high-G-capable aircraft. When multiple factors are present, the risk is cumulative. The most obvious factor is the maximum G level to which aircrew are exposed. In the USAF, pilots are told to limit themselves in the most advanced fighters to +9 Gz. Some USAF aircraft have intrinsic software that prevents it going above +9 Gz. In aircraft without this technology, it is possible to exceed the +9 G limit; when this occurs, the aircraft must be assessed for damage after landing, and often the aircrew are required to present for assessment as well. Other important parameters include Onset Rate (G per second) and duration of continuous G exposure. Additional factors include: number of high-G exposures in a given sortie, number of high-G exposures a week, and number of high-G exposures over the duration of a career. As the value of each of these individual factors increases, the risk of neck injury increases as well.

   c) Mission profile is another contributing factor to neck pain. While +Gz represents the primary stress axis, a mission with many aggressive fighter manoeuvres may result in a combination of multiple G vectors, e.g., in the X axis (front to back, back to front = heart to spine axis) and Y axis (side to side = shoulder to shoulder axis). Although less so than Gz, Gx and Gy force vectors are also considered to be risk factors for neck injury.

   d) In multi-seat high-G aircraft, those who are not controlling the plane have an additional risk because they may not be anticipating each exposure to G or have time to prepare before G onset. If these crewmembers are caught unprepared for the onset of high Gs and do not have time to adopt optimal posture and head position, their cervical spine structures are more likely to be subjected to severe asymmetric forces that could result in injuries.

   e) G-induced Loss Of Consciousness (G-LOC) is another risk factor for injury. G-LOC causes include: lack or improper use of anti-G straining manoeuvres during high-G onset or high-G loading for long duration, either because it was not anticipated or thought to be not required; lack of proper anti-G straining manoeuvres (lack of experience, improper technique or too fatigued to execute properly); and Anti-G Suit malfunctions. During G-LOC, there is no longer positive control of posture or head position and the head will move passively as a result of external forces experienced – this can cause injury when one's normal range of motion is exceeded by the G forces and/or there is no active deceleration/resistance to speed of movement while unconscious.

f) Injuries can include nerve impingement, with or without cervical disc herniation, resulting in neck pain as well as arm pain, numbness, and weakness (usually unilateral). Even without the pathology above, pain can result from muscle strain, which may develop as one contracts muscles against G forces in order to maintain head position or in order to move the head.

g) Current ejection seat designs emphasize restraint and maintaining the correct spinal and head alignment during the phases of ejection, i.e., catapult, windblast, and parachute opening shock. The original design did not take into account in-flight refuelling and assumed that a typical flight would only last approximately an hour. Therefore, ejection seatback angles and cushions are not ergonomically designed for longer duration flights and the resulting posture and spinal position may contribute to spinal pain.

1) **Neurology** refers to how the spinal cord and spinal nerves can be irritated or injured, and how to recognise the signs and symptoms of such. When aircrew understand more about what pain is and how it works, it can reduce the "threat value" of pain and therefore can help reduce pain itself.

2) **Nutrition** refers to the optimal mix of macro and micro-nutrients for a given person's specific physiology and specific activities. The body requires proper nutrients to perform well, recover from repetitive stress and resist injury. See Section 4.2.2.2.2 for additional details.

3) **Preventive exercises** refer to any exercise that may mitigate or prevent pain and/or injury. These exercises can be divided in those that increase physical capacity (see Section 4.3 and Annex E) and exercises that can be performed immediately before flight, in flight, and immediately after flight. As non-flying activities also impact flying physical performance, core and trunk exercises for general fitness and participation in sports activities are necessary.

a) Aircrew are taught to perform a pre-flight warm up (dynamic stretching exercises) and a post-flight cool down (static stretching exercises) to promote recovery.

b) Aircrew are also taught exercises/movements (controlled range of motion stretching) they can do in-flight (as close as practical) prior to initiation of manoeuvres under G. These are also intended to prevent/mitigate injury.

c) After extended periods of flying, the postural muscles may become fatigued and agitated, therefore, aircrew are taught to perform additional movement/stretching when safe to do so. These are intended to assist in maintaining concentration by alleviating tension.

1) **Recovery methods** refer to what a person does (and does not do) following a given activity in order to minimise the time to return to baseline physiology. An example would be a schedule of gradual return to normal training following the running of a marathon. In aviation, when operational tempo permits, there should be a rest period following a period of night flying to allow the body to recover from repetitive exposure to increased stress (weight from NVGs) on the neck.

2) **Work-rest cycles** refer to how to intersperse work with rest and sleep. This includes, but is not limited to, knowledge of sleep hygiene, daytime breaks, and pacing oneself. Ensuring that the body has an opportunity to rest during the work day reduces the cumulative effects of repetitive stress, thereby reducing the risk of injury. See Section 4.2.2.2.4 for additional details.

3) **Physical training programmes** refer to a set of prescribed physical activities to mitigate or prevent pain and/or injury. See Section 4.2.2.2.3 for operational considerations.

a) **General physical training programmes** refer to programmes that include exercises that benefit the entire body. The purpose of such training programmes is to increase and/or maintain the overall physical fitness.

b) **Neck-specific training programmes** refer to doing programmes that include exercises that target the neck. The purpose of such training programs is to increase/maintain the functional capacity of the neck. These programs include exercises to improve mobility, motor control, proprioception, coordination, endurance, and strength.

c) **Individually targeted general physical training programmes** refer to programs which are customised for a specific individual. The advantage of individual tailored programs is that they will include exercises which focus on correcting the physical deficiencies of each individual.

d) **Individually targeted neck-specific training programmes** refer to exercise programmes which are also tailored to a specific individual and include exercises that target the neck. For an individual with neck pain, this is the most advantageous type of programme as it will focus on exercises to address the neck pain/injury in that specific individual.

e) **Specific sports camps for aircrew** refer to actual participation in an immersive training environment for a specific period of time, such as an eight hr/day soccer camp for one week. The aim of a sports camp is to give an introduction of a Professional Athlete Model for aircrew (see Section 4.2.3). These also provide more understanding about exercises, how targeted training programs work, and how aircrew can develop specific skills. Aircrew are given education of "preseason training" in order to gain knowledge, how to improve and maintain flight crew performance, and prevent injuries. The topics of these camps also include "pregame" (i.e., pre-flight) preparation and recovery methods. Additionally, neck- and back-specific training methods are supervised.

   i) The baseline trend in physical condition has been declining among pilot trainees in the Finland Air Force Academy. This is parallel with development of physical activity in general population. It has been reported that repeated sports camps with education and testing has improved physical conditioning during flight training [6].

   ii) The German Armed Forces gives all their aircrew (fast jet, rotary, and transport) the opportunity to take advantage of a three-week preventive programme in specialized hospitals every four years starting at the age of 28 years. The prerequisites for this are that the aircrew member has completed their flight training for at least three years and still has at least one year of remaining service. This treatment in specialized facilities includes a personalized sports programme, different kinds of physical therapy under medical supervision and, if necessary, psychological counselling [7].

4.2.2.2.1 Effects of Acceleration

The effects of acceleration uniquely impact spinal loading in fast jet and rotary-wing aircrews. This section discusses policy and research by the Finnish Air Force to determine the effects of cumulative exposure to +Gz loading. See Table 4-2 for a summary of the NATO nations' fast jet aircraft guidance/policies.

4.2.2.2.1.1 Finnish Air Force Restrictions in Aeromedical Certificate

Finnish aircrew with prolonged symptoms are reviewed in a multidisciplinary board, where the cases are referred by the treatment or examination flight surgeon. The board consists of all flight surgeons and physiotherapists from squadrons and the Aeromedical Centre, spine surgeons (orthopaedic and neurosurgeon), consultants of physical medicine and rehabilitation, neuroradiologists, and other consultants if needed (e.g., neurologists or aviation psychologist). The board is chaired by the Finnish Air Force Chief Flight Surgeon. The aim of the board is to seek an individualised optimal treatment and rehabilitation path. Procedural limitations case by case are also discussed.

Table 4-2: Summary of Aircraft Acceleration Limitations.

Country	Fast Jet Aircraft Guidance/Policy	Rotary-Wing / Multi-Engine Aircraft Guidance
United Kingdom	Release to Service (for Typhoon only) provides a warning to aircrew that "manoeuvres flown above 4 G with NVGs donned pose a significant increase in risk of neck injury" No restrictions on use of NVGs in other Fast Jet (FJ) aircraft using NVGs	None
United States Navy	None (Hornet capable of +7.5 Gz)	None
Finland	Maximum +6 Gz with NVGs down locked Maximum +3 Gz with NVGs locked up No restrictions with other helmet-mounted displays Other limitations: See 4.4.1.1 about Procedural limitations	None
Belgium	No specific G limitations (Basic Fighter Manoeuvres not performed at night, so G is usually limited to 5 – 6 G)	None
Netherlands	3 G restriction when flying with NVGs in the up position	None
Germany	EUROFIGHTER (air policing only): 4 G limit with NVGs in the up position and 6 G when lowered (due to the helmet limitations, not neck pain)	None

In a case of persistent flight-related neck symptoms, there is a need to restrict and diminish the occupational loading, from both an aeromedical and administrative point of view. The aim is to keep injured, usually experienced, pilots actively flying in squadrons in non-deployed roles and utilise their experience, if medical condition allows it. Gz limitation is adjusted individually to achieve a flight envelope where the pilot remains asymptomatic until full function is restored, whenever operationally feasible, so as to ultimately reduce cumulative neck loading.

Squadron-level flight surgeons are authorised to set medical certificate restrictions up to one month, Finnish Air Force Chief Flight Surgeon up to three months, and longer medical certificate restrictions are set by Air Force Command Finland. Permanent medical certificate restrictions are signed by Commander of Finnish Air Force and operational risk evaluation is always part of aeromedical analysis. Spinal disorders are the most common reason for aeromedical limitation in the Finnish Air Force (FINAF).

4.2.2.2.1.2 Fatigue Index

Data of flight hours and Fatigue Index (FI) collected from every flight was obtained from the FINAF flight data recordings. FI was originally invented in 1970s by SAAB flight engineers in order to follow aircraft

(J35 Draken) structural fatigue due to in-flight acceleration forces. Since 1995, Gz loads of FINAF jet aircraft BAE Hawks and F/A-18C/D Hornets are recorded into the database, which can also be used identify aircrew sortie by sortie. FI is determined by the number of times -1.5, 0.5, +0.25, +2.5, +3.5, +4.5, +5.5, +7.0 and +8.0 Gz levels are exceeded during the sortie. These values are recorded by the aircraft's accelerometer, stored in the flight data recorder, and FI is computed using these values.

There are different kinds of formulas for different models, wing modifications, part of fuselages, etc. The BAE Hawk mk51 formula for pilot tracking was chosen in the present study, because pilots have started their jet flight training since 1995 with this aircraft type.

The sum of FI values from sorties provides a figure representing cumulative Gz exposure. Cumulative exposure for Gz is then determined per 1000 flight hours. 13 FI/1000 flight hours is used as a suggested maximum for follow-up pilots' annual exposure. This figure comes from certain values for structural fatigue follow-up. However, this 13 FI is not a constant maximum that a pilot must not exceed. The system is introduced to increase pilots' and squadron leaders' awareness who may be at risk due to intensive loading, and to be a tool for optimal work/rest scheduling in order to manage occupational loading.

The limitation of this method is that the system only records how many times given thresholds are exceeded. It does not take into account the duration time above the Gz peak if the next threshold is not achieved. However, it was considered that FI is a useful tool to follow-up pilots' cumulative Gz exposure. It gives far more accurate data for different levels of loading during each sortie and cumulative Gz loads than just flight hours as the acceleration forces varies greatly sortie by sortie.

4.2.2.2.1.3 Gz Limitation and Its Effect on Cumulative Loading

As seen in Figure 4-2, Gz limitation is an effective way to diminish Finnish pilots' occupational loading and still keeps pilots in active squadron flying duties. Despite the level of G limitation (+2 Gz to +6 Gz), it reduces the peak forces and FI is clearly lower during follow-up after setting the limitation. The FI curve declines starting a couple of years before the Gz limitation was set. This is probably due to developed symptoms and self-restricted loading or possible temporary flying restrictions before permanent limitation.

The FINAF decision on permanent limitation takes into account operational requirements and, while this impacts the ability to use these pilots in full spectrum, it is considered more efficient to keep them in squadron and be able to use their experience where it is needed, even if they are not deployed.

4.2.2.2.1.4 Cumulative Fatigue Index

Cumulative Gz exposure and its effect on degenerative changes and spinal symptoms were examined in two studies in Finland. The first study population consisted of twenty-three pilots flying with Gz limitation due to spinal disorders and fifty experienced (greater than 1000 flight hours) symptomless controls flying actively in operational missions. Data obtained for all subjects included the level of cumulative Gz exposure measured sortie by sortie with FI recordings and flight hours during the first five years of the career.

The mean (±SD) accumulation of FI in the first five years of flying high-performance aircraft was 8.0±1.8 among the pilots in the Gz limitation group and 7.7±1.7 in the control group. The results of this study do not support hypothesis that early career +Gz exposure level (FI or flight hours) could predict future flight limitations. +Gz exposure level (FI or flight hours) could predict future flight limitations. In another study, all Finnish Air Force pilots who have waivered to fly jets only up to a limited Gz level and who have started jet flight training between

1995 and 2015 were included in the study. They were matched with two controls each within similar training syllabus and follow-up time of up to the cases' endpoint.

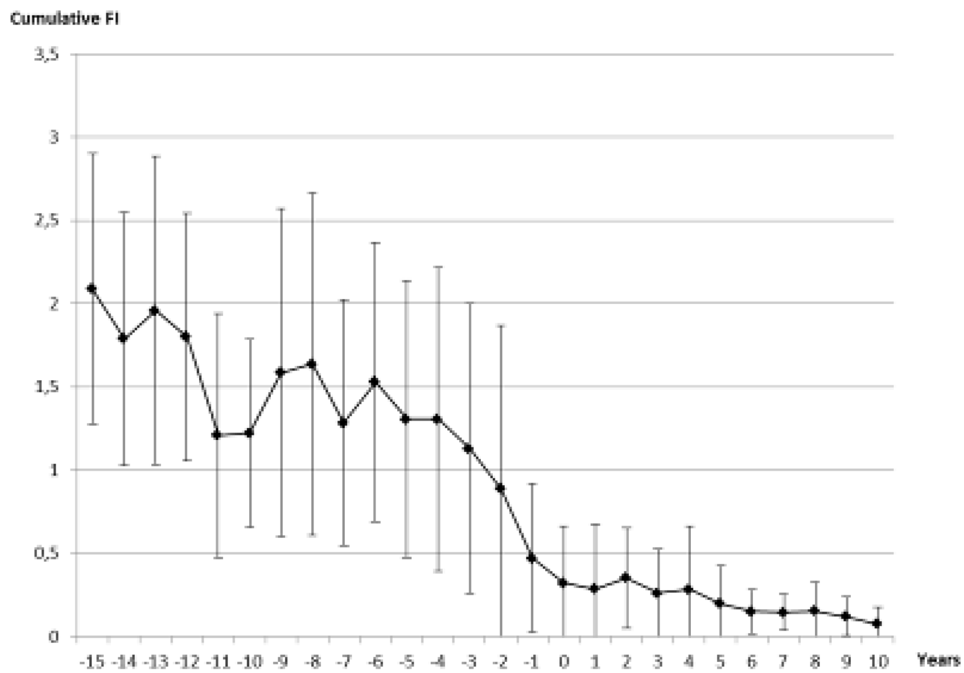

Figure 4-2: FI and Gz Limitation: All Finnish Air Force Pilots Who Have Waivered to Fly Jets Only Up to Limited Gz Level and Started Jet Flight Training Between 1995 and 2015. 0-point is the year when permanent Gz limitation is set. (Data of Finnish Air Force Communications (FINAFCOM)).

Flight data was collected from Finnish Air Force Flight Database. All jet flights flown by study subjects between 1995 and 2015 were included into the analysis. Data included a flight day, the length of the flight, the number of exposures of certain Gz levels achieved during a flight and measured Fatigue Index per flight. Then, cumulative loading of FI was collected in annual cohorts.

There were no statistically significant differences between groups over the follow-up period in annual FI (see Figure 4-3).

4.2.2.2.1.5 In-flight Intensity Analysis

Muscular loading induces muscle fatigue. Muscular recovery after exercise takes place in a pattern that includes inflammatory phase, repair phase, and then maturation and remodelling of muscle cells. Recovery from loading takes 24 to 48 hours, and if tissue is injured, it may take weeks [8], [9]. There is also similar evidence in aeromedical settings [10], [11].

Flight intensity in terms of amount of days between more strenuous flights (flights with FI > 0.013) in the FINAF dataset were analysed up to the waiver date. There was no statistically significant difference between waiver group and controls in the amount or distribution of recovery days over follow-up period (Figure 4-4). This does not support the hypothesis that pilots who got degenerative spinal disorders would have had more intense flying periods during their career and this insufficient recovery of muscles would play a role.

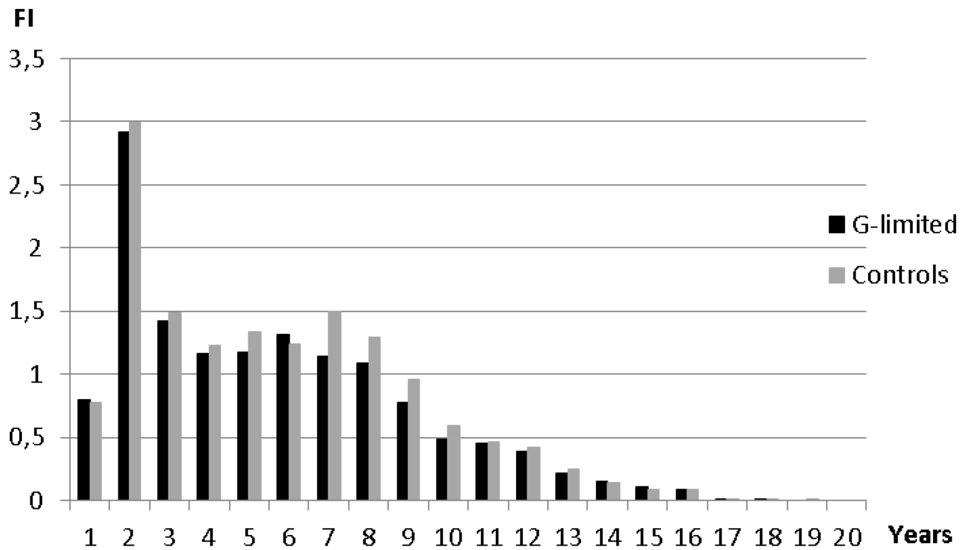

Figure 4-3: Annual Cumulative Gz Exposure. Data includes whole-career flight data of all waivered pilots and their matched controls. (Data of FINAFCOM).

4.2.2.2.1.6 Survival Analysis

As seen in Figure 4-3, pilots' cumulative dose of Gz varies year by year. However, this seems uncorrelated with developing severe musculoskeletal disorders among fighter pilots. The linear survival curve in Figure 4-5 indicates that degenerative changes developing in spine occur place slowly and take place across different phases in the training syllabus. There are no single or multiple breaking points where the dose of loading affects the human spine.

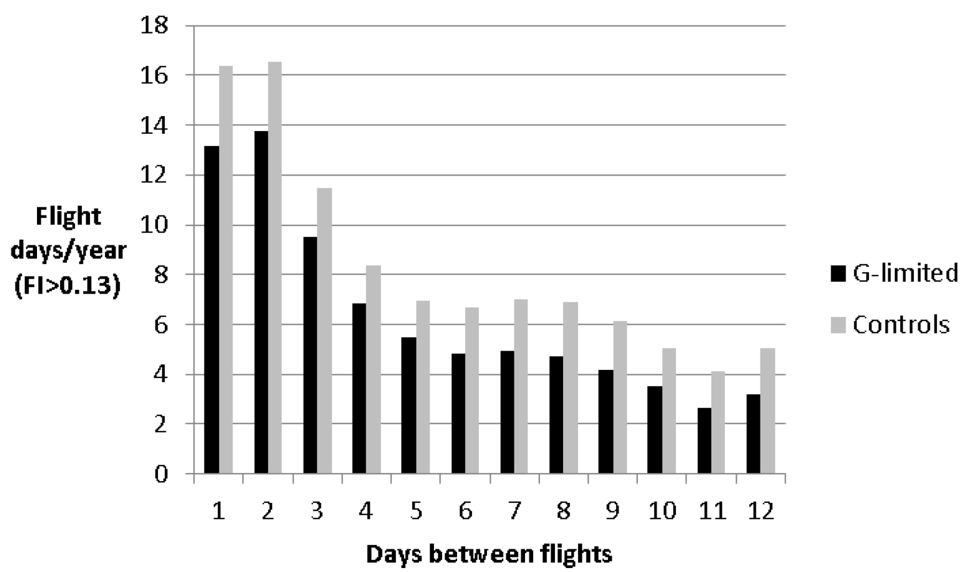

Figure 4-4: Recovery Days Between High-Gz Sorties. Data includes whole-career flight data of all waivered pilots and their matched controls. (Data of FINAFCOM).

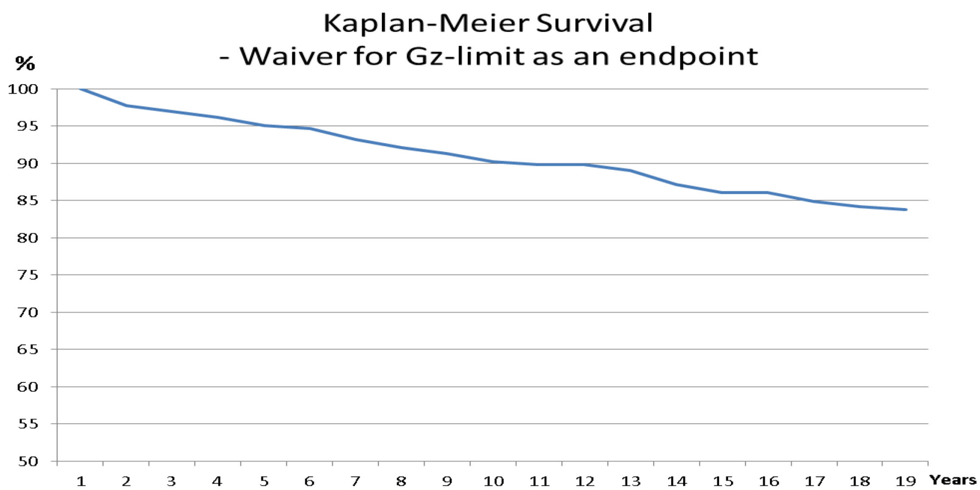

Figure 4-5: The Endpoint in Survival Analysis Was Set to the Date When a Pilot Was Waivered with Gz Limitation. Follow-up time started from the first jet trainer flight. Here all pilots who have started jet training between 1995 and 2015 were included in the survival analysis. (Data of FINAFCOM).

4.2.2.2.1.7 Cumulative G Summary

When one flies high-performance jets long enough, degenerative changes occur due to the Cumulative Loading Effect and ageing.

Those who get severe symptoms during their career do not fly more strenuously than others.

It appears that the amount of cumulative +Gz exposure during the first five years of fighter pilots' training syllabus nor a career long cumulative loading are not an individual risk factor for spinal disorders leading to flight duty limitation.

The flight intensity, in terms of periods in which pilots often fly more high-Gz sorties and have shorter recovery periods between flights, seems to have no role for developing severe musculoskeletal disorders leading to permanent flying restrictions.

4.2.2.2.2 Food and Nutrition

The nutritional recommendations for pilots must be divided in three distinctive periods. Each period has specific aims and requirements: nutrition between flight, nutrition before flight, and nutrition during flight.

In contrast with the two last categories, the nutrition between flights must follow the general recommendations for healthy food. The aim of the two last categories, i.e., nutrition before the flight and nutrition during the flight, is to help the pilot to optimise their performance. To do this, a functional nutrition is more appropriate, i.e., an optimal nutrition aiming to the demanding task. Such a functional nutrition can be divergent of general recommendations for healthy food.

4.2.2.2.2.1 Nutrition Between Flights

The basis of a healthy diet for a pilot is an appropriate selection of foods and beverages and a proper hourly distribution of the meals [12], similar to that recommended for the general population. An ideal diet should be varied and balanced, with a constant supply of energy macronutrients, such as carbohydrates, lipids, proteins, and non-energy food, like water, minerals, and vitamins with an adequate intake of fibre. However, findings from nutritional research suggest that pilots do not have diets that meet normal dietary guidelines [13]. There appears to be a need for nutrition education, dietary modification programmes, and further study of the diets of fighter pilots.

Vitamins and minerals are essential in the diet and their requirement may be satisfied widely, with relative quantitative and qualitative adjustments from the normal diet ration without any need for supplementation, except in rare cases. One study showed that dietary calcium in pilots did not meet the military recommendations (84% of the recommended level) [14]. Renal excretion rates of sodium and water increase during acute hypoxia exposure and increase in ventilation in response to hypoxia, accelerating fluid loss [15], [16], [17]. The foods with the highest mineral content are water, fruit and vegetables, but also some animal products have good bioavailability.

Vitamins, introduced with food, are essential for good health. Again, a varied diet contains a sufficient supply of vitamins. The vitamin content in food depends of numerous factors, which depend not only on the type of food, but on environmental factors, production, and conservation. The choice of fresh and seasonal or unrefined food certainly helps in a good bioavailability of these micronutrients. Lindseth and Lindseth [18] found a relationship between airsickness in female pilots and a diet low in vitamin A, vitamin C, and iron; therefore, it is suggested that females increase their intake of these nutrients. Taking vitamin supplements should be discouraged; it is most useful to increase the consumption of food at greater content of these nutrients. Many supplements may be contaminated or of unknown composition and dosage, therefore, pilots should avoid taking any pills.

Dietary fibres are plant-derived substances resistant to digestion and essential for the well-being of the body through functional or metabolic processes, regulating the passage of food in the gastrointestinal tract and assimilation of nutrients. One study showed that dietary fibres in pilots did not meet the military recommendations (53% of the recommended level) [14]. Pilots can gain many benefits from a diet high in fibre, the same specifications as for the general population.

In summary, one way to meet the required combination of nutrients for aircrew would be to encourage a model based on the types of foods included in a Mediterranean diet. Therefore, the diet should be adequate to meet energy expenditure needs, without exaggeration, varied and well distributed throughout the day. Food choice is often subjective and related to daily tasks, but it is useful for pilots, that could be called upon to perform duties on a moment's notice, to divide it into several parts (5 – 6 times per day) to avoid overloading the digestion and adequate nutrient distribution throughout the day. It is important to promote good hydration, adequate glycogen stores through carbohydrate intake depending on the amount of physical and mental effort proposed, preventing blood sugar spikes or hypoglycaemia and paying attention to the food digestibility and its quality, avoiding any condition of intestinal discomfort, e.g., with excess fibres before flight. After each flight, the greater concern must be to reintegrate the loss of water, salt, and the depleted sugar during physical efforts.

4.2.2.2.2.2 Nutrition before the Flight

The last meal before the flight is important to allow the pilot to execute their task in optimal conditions. This meal must have different composition and priorities compared to general nutritional recommendations. Being lightly digestible, low in fibres, low in fat and proteins, and rich in complex carbohydrates are basic requirements for the meal before the flight. A limitation of fibres and fat is important for digestibility and to limit stool incidents during the flight. Complex carbohydrates allow a maximal replenishment of glycogen stores in muscles and liver; and providing a glycogen-based energy supply during the flight.

4.2.2.2.2.3 During the Flight

The food consumed during the flight has additional requirements as the meal before the flight. The food must be compact and pliable, resistant to pressure, easy to consume, low in waste, and not crumbling. Additionally, adequate hydration must be provided, but due to the limited possibilities to evacuate urine, an optimal hydration will be difficult. There are just few studies on the diet's effects on pilot performance [14], [19], [20]. Daily water requirement is indicated in about 1.5 – 2.5 litres per day. Flight activity results in a significant loss of water, because the air-conditioned breathing through the mask dehumidifies the mucous membranes. The absence of sufficient hydration can reduce physical performance and lengthen the recovery phase. Studies showed that flight performance and spatial cognition test scores were significantly poorer for pilots who had low fluid intakes and experienced dehydration in comparison to hydrated pilots [21]. Moreover, it has been observed that dehydration in crewmembers of high-performance aircraft causes an unexpected diminution of their normal G tolerance and a reduction in peripheral vision [22], [23]. Rehydration has a positive effect with cognitive performance returning to normal very quickly. In fact, the pilots who have experienced changes in peripheral vision due to dehydration notice an immediate improvement in vision after consuming fluids [23]. Therefore, good hydration is encouraged for most flights. Pilots should not wait until they are thirsty to consume fluids and because so many factors can influence hydration status on a flight, it is important for them to hydrate before the flight [24].

During flights, pilots have to consume the right quantity and quality of carbohydrates. A diet with low carbohydrate content can cause difficulty in stabilization of blood sugar, in particular during acute exposure to altitude [16] and increase the onset of fatigue [25], [26]. The daily intake of carbohydrates should be made for the most part (about 80%) from complex carbohydrates, which will reduce sugar intake, thereby avoiding blood sugar spikes.

The role of proteins during flights is controversial. Pilots consuming a high-protein diet had significantly poorer overall flight performance scores than pilots consuming high-fat and high-carbohydrate diets [27]. Research suggests that high intake of protein and fat should be limited before some physical activity because they take longer to digest.

The food requirements during the flight are comparable with the requirements in some sports, as for example for cyclists. Therefore, the same approach can be used to fulfil those requirements with, for example, energy gels, caffeine gels, power gel, and other semi-liquid foods with a double role: providing energy and liquid. However, prior to recommending energy gels or caffeine gels, pilots should receive education/explanation on their pros and cons.

4.2.2.2.3 Operational Considerations for Physical Conditioning Programmes

4.2.2.2.3.1 Personal Factors

For successful implementation of pain mitigation initiatives that require active aircrew participation, (e.g., a physical conditioning programme), personal and operational factors that influence aircrew compliance must be considered as part of the overall strategy.

4.2.2.2.3.2 Command Commitment

To realize the potential benefit, commanders should view the participation in physical conditioning as an investment in operational capability, or part of an overall risk-control plan. Command commitment should be clear to all subordinate units, with a formal structure to ensure this command commitment is clear at all levels.

4.2.2.2.3.3 Cultural Change

Aircrew develop certain behaviours and beliefs that impact their personal fitness regimen, and they balance their physical fitness along with their personal life and work demands. However, a culture that prioritises operational capability outputs often sees aircrew de-prioritise their fitness activities during periods of high operational tempo. Efforts to impose a physical conditioning programme may initially be met with some resistance and push-back, often in response to perceived interference with operational capability. A culture that prioritises physical fitness and conditioning – especially during period of high operational tempo – will develop organically as students and early-career aircrew develop good fitness practices, and appreciate these as a way to promote and sustain their operational effectiveness. When introducing a physical conditioning programme, much effort should be focussed on the development of optimum fitness behaviours in junior aircrew, and supporting these behaviours throughout their career. Cultural change can be encouraged with clear command commitment, and clear articulation of physical conditioning as an investment in promoting and sustaining operational effectiveness.

4.2.2.2.3.4 Compliance

Notwithstanding the evidence basis for particular initiatives, their potential benefits are eroded if there is little uptake and compliance by aircrew at risk of flying-related neck pain. A comprehensive review of organisational and personal factors that interfere with compliance must be addressed, and the initiatives should be developed into a format that can easily be adopted by aircrew to maximise their participation. Consideration might include operational tempo, operating hours, proximity to the flight line, and flexibility in the strategies to accommodate different operational demands in a manner that can be integrated within the unit battle rhythm.

4.2.2.2.3.5 Educational Support

Education support to promote a better understanding of the reasons for a physical conditioning programme is vital to compliance. Aircrew must understand not only HOW to undertake the conditioning activities, but appreciate WHY this is important in terms of reducing their risk of injury. Put simply, aircrew who believe that physical conditioning is an investment to allow them to fly more comfortably, improve their operational performance in flight, provide them with a competitive advantage in combat, sustain their operational effectiveness, extend their flying career, and generally improve their quality of life by reducing flying-related neck pain are more likely to engage with a conditioning programme and be compliant; aircrew who do not believe this will only participate within the constraints of legislated participation.

4.2.2.2.4 Rest

One feature often overlooked during flight operations is recovery time or simply rest. While this can be a challenge given operational tempo requirements, it is essential to balance work and rest to avoid an over-stress condition that can reduce both physical and cognitive performance. The concept of recovery is necessary for the removal of metabolic by-products of fatigue, e.g., lactic acid accumulated during physical work. Over-stress exceeds the capacity of an individual to adapt and leads to a deterioration in the performance and physiological capabilities, such as alterations of the responses of the endocrine and autonomic nervous system and suppression of the immune function, increasing the risk of infections and diseases. While a normal recovery could require some hours or days, if one runs into over-stress, a full recovery will take much more time. Symptoms of "over-stress" are very subjective and can include sleep disorders, irritability, lack of motivation, difficulty concentrating, changes in appetite, and loss of body weight. The best detector of over-stress syndrome can be a deterioration of performance. The pilot must be able to manage their activities and mental commitments in the best way to avoid endangering the pilot's life and their colleagues.

4.2.2.2.5 Respiratory Education – Difficulty in Breathing and Cervical Disorders

Tom Myers, in his book "Anatomy Trains" establishes the links or lines of the fascial system between the neck and the rest of the body and how they are important for functional mobility of the musculoskeletal system [28]. Moving to the fascial links, it is important to consider that the fascia is a system with proprioceptive properties and provide significant peripheral information, as well as having a probable nociceptive function. Further, the fascial tissue possesses fibres capable of contracting, probably causing spasms, followed by dysfunction and pain. An important fascial system is the Thoracolumbar Fascia (TLF), which develops posteriorly from the sacral region through the thoracic region, and finally to the cervical region. For example, diaphragmatic dysfunction negatively affects this tissue, leading to central and peripheral symptoms. Cervical pain can have diaphragmatic causes, and has repercussions for the neck through the TLF. This is a bidirectional process [29]. Moreover, diaphragmatic tension, resulting in reduced range of motion and its function, must be replaced by the work of accessory respiratory muscles, i.e., some cervical-occipital muscles, in order to maintain ventilatory capacity, resulting in postural imbalance. In the same way, deep cervical muscle failure and extensor muscles weakness may involve difficulty breathing. Some rehabilitative experiences show a better mobility of the head after respiratory rehabilitation, with a net reduction of cervical pain. It also takes place at scapula-humeral and dorsal portions for the accessory muscles involved [30]. A comprehensive approach must therefore provide a functional recovery of the diaphragm through breathing exercises and stretching the global posterior chain [31].

4.2.3 Professional Athlete Model

Aircrew have become a highly qualified and not easily replaceable part of the weapon system, especially in smaller air forces. New aircraft with their high-G loads and pilot use of advanced helmet-mounted equipment bring human physiology to its limits. Additionally, the increase of computer-based information in new glass cockpits leads to a potential overload of sensory input for aircrew in their workplace [32]. All these factors have changed the way military aircraft are flown. Moreover, it has an impact on the timeframe and training costs in order to become combat ready.

The new requirements had many consequences. Most air forces changed or updated their system of recruiting candidates. They also tried to find ways to consolidate the reliable performance of aircrew and to preserve their physical and mental fitness for as long as possible. Due to the lack of sufficient evidence in many of the studies about prevention of neck pain, some air forces have changed their approach. They are currently implementing methodologies that are assessed by professionals in this field based on the principles of best practices. They are starting to consider their aircrew more like professional athletes and trying to give them the best possible care to enhance their performance [33]. In this model, like professional athletes, aircrew have immediate access to flight surgeons, exercise specialists, physiotherapists, and possibly even access to psychological counselling.

The main purpose in a new model that considers aircrew as professional athletes should be the promotion of one's own professional status awareness, looking for an ideal physical-psychological condition and an appropriate lifestyle [34]. Beneficial effects of exercise on cognitive performance of experienced athletes have been reported for visual attention, visual search, decision making, and choice reaction speed [35], [36], [37], [38]. All these features are essential for flight activity. As a consequence, a significant change in the policy of some countries is necessary, especially in times of reductions in military budgets due to economic conditions.

This approach to the problem can be found is at different levels of maturity in NATO countries. The idea behind this model is that even if it is expensive to have Squadron embedded flight surgeons, sport science specialists, such as trainers and physiotherapists, and easy access to specially trained aviation psychologists, it is less expensive than to lose combat ready pilots due to preventable health problems. Losing only one pilot results in the loss of millions of dollars, which were spent during their training. Teams in most professional sports are working to protect their valuable property, the players, and to make sure that in case of problems, the time away from practice and competition is kept as short as possible. This should be the same goal we have in aviation medicine.

With most professional sports teams it is not enough just to have easy access to a physician. They want to have a doctor present on the side-line to check the athlete in case of a problem as soon as possible in order to prevent further injury and minimise time away from competition. Non-reporting of neck pain and musculoskeletal injuries by aircrew is a known longstanding problem within all stages of the flying career. Reasons for non-reporting previously cited by aircrew include lack of confidence in the availability of aeromedical understanding within the medical departments, especially if the members are not a part of the aeromedical team, fear of formalising the inability to fly, and the forced interruption into the flying programme due to the referral process. In some NATO countries, even the well-accepted principle that the flight surgeons are embedded in Squadrons is not always implemented anymore due to economic conditions. While most countries still maintain the approach of close daily contact between the specially trained flight surgeon and their assigned unit aircrew, some nations have reduced the approach to an assigned general medical practitioner with some specialised training but one who is not working alongside with their assigned aircrew on a day-to-day basis.

So even if this seems minor, in reality there is a big difference between working with aircrew every day or just seeing them when they have a medical problem. These approaches work well if Air Forces, besides getting a quick diagnosis by the physician, also start the treatment as soon as possible [39], [40], [41]. It is even better if Air Forces are able to prevent an injury as do professional teams with a physiotherapist working with the players all the time, tackling their problem areas before they get injured [42]. Currently, some Air Forces have developed an Aircrew Direct Access Physiotherapy Service or embedded a physiotherapist in the Squadrons that offers the opportunity to empower aircrew to self-care and self-manage to meet their individual needs. In general, direct access programmes are associated with no increased demand for services, greater levels of attendance and completion of treatment, and lower medical costs. It encourages aircrew to seek treatment by a trusted healthcare professional that is aviation medicine trained with the knowledge to reduce their suffering, and reduces the risk that aircrew will seek treatment from a non-Service source. For aircrew, a key benefit is that lower levels of work absence are usually required. Experience with this way of handling the problem suggests there are high levels of service-user satisfaction and confidence. Therefore, the physiotherapist is as necessary to the daily business of a team as the physician is.

Like many teams these days that not only have a coach but a multitude of coaching personnel working on the different aspects of the game, some Armed Forces already work with sport science and exercise specialists [33]. They perform an individual evaluation of every (aircrew) member and try to find the problem areas of each one in cooperation with the doctor and the physiotherapist. Aircrew have to know that with increasing age and increasing physical performance demands, training needs to be more specifically aimed at adaptation to the abilities required for the conditions of flying, such as strength, endurance, and joint mobility [43], [44]. This should dissuade aircrew from choosing physical activities and sports autonomously; instead they should consult the exercise specialist or Squadron physician, who can advise on suitable activities to their fitness level and flight profiles. They create specialised training programmes for each individual focused on their needs and problems. This can be done with specialised training equipment or with much simpler equipment like rubber resistance bands, Total-Body Resistance Exercise (TRX) suspension trainers, or even exercises based on the weight of the body itself without specialized equipment, such as in yoga or Pilates. These minimal equipment approaches have the advantage of being easily done in case of a deployed mission.

There are very few studies on the effects of diet on a pilot's performance. However, findings suggest aircrew do not adhere to diets that meet normal dietary guidelines [14], [19], [20]. In a new vision of aircrew as professional athletes, it would help to promote new dietary recommendations by experts best suited to the athletic performance demands, especially during flight and to expand the studies about this. The variables involved in the estimation of energy requirements of aircrew are numerous and depend on factors such as age, the number of hours flown, the type of missions carried out, the surroundings and the lifestyle. This needs the knowledge of an expert to take care of meal plans and teach aircrew about their specific needs.

In summary, a good diet is as important to the pilot as it is to the athlete. The education of the pilots by experts must be one of the goals in this model [45] (see Section 4.2.2.3 Food and Nutrition).

Last but not least, in times of high mental workload, some Air Forces started to work with specially trained aviation psychologists for their aircrew. Especially with a focused mindset like most fighter pilots have, it is sometimes necessary to talk to a member outside of the envelope of his Squadron. This is best accomplished with someone who knows the Squadron problems but is not involved in the Squadron and who "learned" the way to handle these kinds of problems. Especially in case of an accident, in the worst case involving death of comrades, it is a generally accepted fact that physical activity and an early access to a trained person like a psychologist or a peer is necessary to prevent Post-Traumatic Stress Disorder [46], [47]. This can be done by an assigned psychologist who knows "his" pilots and who is readily available due to his assigned status to only a few Squadrons. It is always faster and more effective to know who is responsible for certain Squadrons than to look for someone in case you need them.

4.2.4 Summary of Active Conditioning Programmes Deployed in NATO Nations

Table 4-3 summarises the programmes currently in practice in Australia, Belgium, Canada, Finland, Germany, the UK, and the US. See Annex E for exercise studies in progress.

4.3 NECK EXERCISE STUDIES

4.3.1 General Requirements

There are a number of efforts, both conducted in the past and ongoing, that attempt to quantify the benefits of neck exercise programmes to reduce the incidence, magnitude, and persistence of neck pain. The results have often been mixed. The following section includes lessons learned that will assist in the design and execution of future studies. Note that the requirements outlined below are subject to the rules of the organisation undertaking the research, including compliance with the requirements of the Ethics Review Board overseeing the research.

4.3.1.1 Motivation

a) The need for these studies is derived from surveys and reports from national safety centres providing evidence of loss of aircrew availability due to impairments and disability, reduced mission hours, or reassignment to flight assignment on a less aggressive platform.

b) To be successful, a validated training programme should be developed and instituted early in an aviator's career to reduce probability of developing neck disorders and cervical pain and/or the magnitude and persistence of pain when it arises.

c) Any programme must accommodate national training/fitness/financial resource/operational requirements.

Table 4-3: Deployed Conditioning Programmes.

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
NAME OF PROGRAMME						
Aircrew Performance Enhancement Program (HPEP – Fit4Pilot)	RCAF ACP	Military pilots' physical performance	Human Performance Enhancement Program (HPE)	Aircrew Conditioning Programme (ACP)	Physical Conditioning and Injury Mitigation Programme (PCIMP)	I: Fighter Aircrew Training II: ViperNHEXS (Neck Health and EXercise Strategies): Luke AFB, Arizona only III: Contract ACP: Portland Air National Guard Base, Oregon only IV: USAF Physical Therapist ACP
DATE OF RELEASE						
Nov 2016	2018	Jan 1996	Jan 2012	Jan 2012	Jul 2017	I: ~1990 II: 2013 III: 2016 IV: 2017
AIRCREW INVOLVED						
Student pilots, on request for Ops Pilots (Fast Jet and Rotary)	I: Rotary II: Student Pilots III: All aircrew	Fast Jet and Rotary	Fast Jet, Rotary and Transport	Fast Jet, Rotary and Transport (from Royal Air Force, Royal Navy and British Army)	Fast Jet (soon Mobility, Basic Training and Rotary)	I: Fast Jet II: Fast Jet III: Fast Jet IV: Fast Jet and Rotary

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
IS THE PROGRAM MANDATED?						
Mandated and supervised during pilot training in BEL, individual responsibility to continue the conditioning programme during pilot training abroad	I: No II: No III: As per RAF	Annual assessment is mandatory, training is as required	Annual assessment is mandatory, training is as required	Mandated for all aircrew during entire flying training (Fast Jet, Rotary and Transport) Recommended for all aircrew operational flying	During flying training – minimum 2 conditioning sessions per week (4 recommended)	I: Only annual assessments II: No III: No; up to Squadron Commander IV: No
					For operational aircrew – minimum 2 conditioning sessions is aspirational target (4 recommended) Baseline 12-week DAVID spinal conditioning programme is mandatory for all aircrew, then used on an “as required” basis	
ASSESSMENT						
Cervical Spine Isometric Strength						
MVC using Multi-Cervical Unit (MCU) for flexion, extension, lateral flexion in neutral position, in 25° and 45° left and right rotation	I: Self II: Self III: As per RAF	Functional screening, 1 min isometric test for neck, 3 min test for spine extension and flexion	Maximal isometric voluntary contraction 2 x 5 s sitting in neutral spinal alignment with 15 – 20 s recovery (Schnell) flexion, extension, lateral flexion and rotation	MVC using Manual Muscle Tester, 3 x 5 s sitting in neutral spinal alignment with 30 s recovery, into flexion, extension, lateral flexion, anterior 45° lateral flexion, and posterior 45° lateral flexion	DAVID Spinal Conditioning Equipment Isometric Screening	I: Not included II: Self III: Yes IV: Self

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
Cervical Spine Sub-Maximal Endurance Strength						
Anterior/Posterior/ Suboccipital stabilisers (30 sec)	Not included	Not included	Not included	Not included	DAVID Spinal Conditioning Equipment Isometric Screening	Not included
Cervical Spine Range of Motion						
Using MCU and Zebris for flexion/extension/lateral flexion/rotation	I: Self II: Self III: As per RAF	CROM meter – functional screening	Using Schnell Training and Analysis for Cervical Rotation	Using CROM device – flexion/extension/lateral flexion/rotation	DAVID Spinal Conditioning Equipment ROM assessment	I: Not included II: Self III: Yes IV: Self
Whole-Body Flexibility and Mobility						
Functional Movement Screening	I: Self II: Self III: As per RAF	Functional Movement Screening	Functional Movement Screening	Functional Movement Screening	Functional Movement Screening	I: Not included II: Not included III: Yes IV: Not included
Aerobic Capacity						
Physical Evaluation Fitness Test: 2400 m/L and R side bridge	Annual FORCE Test	Cycle ergometer test min. 3.4 W/kg (45 ml/kg/min), fast jet, 3.2 W/kg rotary wings	Running-Based Aerobic 1000 m Test (part of mandatory Basic Fitness Test)	Mandatory military fitness test includes multi-stage fitness test / 1.5-mile run, push-ups, sit-ups (not officially part of ACP)	Annual Physical Fitness Test – 2.4 km run Basic Operational Standard with aspirational target of Specialist Standard for FJ aircrew	I: 1.5-mile run II: Not included III: Yes IV: Not included
Anaerobic Capacity						
Not included	Annual FORCE Test	Maximum cycle ergometer test	11 x 10 m sprint (part of mandatory Basic Fitness Test)	Running-Based Anaerobic Sprint Test (RAST) 6 x 20 m sprints	Not included	Not included

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
			Strength			
MVC and isokinetic strength for abdominal and back muscles on Cybex Norm	Annual FORCE Test	1 min test for sit-up and push-up Standing long jump	Peak muscle power with Schnell 4 Back FPZ system	One-repetition maximum for double leg press, flat bench press	Weights-based individual strength assessment	I: Push-ups II: Not included III: Yes IV: Not included
			Coordination and Balance			
Using Zebris device; find neutral position after submax, flexion-extension movement (10x) and after submax, left-right rotation movement (10x) find angle of 30° rotation right (5x) and 30° rotation left (5x)	Not included	Not included	MFT Fit Disc	Not included	Not included	I: Not included II: Not included III: Yes IV: Not included
			FREQUENCY OF ASSESSMENT			
At start of pilot training, at the end of pilot training, every 5 years	I: Annual Periodic Health Assessment II: Annual Periodic Health Assessment III: As per RAF	Annual	Annual	At start of each phase of flying training (minimum of annual)	During training, additional Physical Fitness Tests (PFTs) are conducted at each training unit During the Tactical Weapons training phase of lead-in fighter training, screening is conducted on arrival and 12 weeks later prior to the commencement of the high-G phase (BFM/ACM)[1]	I: Annual II: Not specified III: Multiple per year IV: Not specified

[1] Screening includes PFT, weights-based strength testing, and spinal strength, endurance and mobility assessments using DAVID equipment. Screening data is used for individual risk of injury assessments prior to high G phase.

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
EXERCISES						
Neck Strengthening						
Neck-shoulder exercises based on individual clinical assessment, progression: i) neutral posture; ii) neck-shoulder stability and motor control exercises, iii) low-load neck strengthening with elastic exercise band, iv) neck strengthening with pulley combined with upper body movements with weights	I: No II: No III: As per RAF	After and before flight training programme, preventive training group	Neck stability exercises with TRX Suspension Trainer (isometric strengthening) and bodyweight exercises	Neck-shoulder exercises based on individual clinical assessment, progression: i) neutral posture, ii) neck-shoulder stability and motor control exercises, iii) low-load neck strengthening with elastic exercise band, iv) neck strengthening with pulley combined with upper body movements with weights	DAVID Spinal Conditioning Equipment Program Neck-X Programme for trainee aircrew	I: Recommends, but current instruction has no specific guidance or exercises II: Yes III: Yes IV: Yes
Strength Training						
Under supervision of PTI	I: No II: No III: As per RAF	Sports camps; after tests in camps, personal training programme Exercises include whole-body compound movements, Olympic-type exercises, which include squats, deadlifts,	Exercises include whole-body compound movements (bodyweight) like freeletics or plyometric training and functional training/crossfit with kettlebell/barbell	Exercises include whole-body compound movements, Olympic-type exercises which include squats, deadlifts, bench press, bent-over row and push press	Sessions – leg and torso functional movement-based strength training; includes squats (front and back), lunges, deadlifts, bench press, shoulder press, bent-over rows, pull-ups, etc.	I: Weight training and push-ups II: (To be used with whichever USAF programme is in use at the time for whole-body strength training and aerobic conditioning)

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
			Strength Training cont'd			
		bench press, bent-over row and push press	First technique training followed by strength training	Exercises progress from initial technique instruction, developing technique competency, then progression of weight whilst maintaining technique	Exercises progress from initial technique instruction, developing technique competency, then progression of weight whilst maintaining technique	III: Yes IV: (To be used with whichever USAF programme is in use at the time for whole-body strength training and aerobic conditioning)
			Core Strengthening			
Core stability exercises based on individual assessment and progression Exercises progress from maintaining a neutral posture in all positions, to static rotation control in all positions, to dynamic rotation control on a stable base, then on an unstable base with weight as required	I: No II: No III: As per RAF	Preventive training group up to 2x/week by Physiotherapist	Stability training for the trunk, shoulder and neck with bodyweight, TRX suspension trainer and Togu (unstable base) Exercise in all positions static and dynamic (rotations); first of all on a stable base, then on an unstable base	Stability exercises for the trunk, shoulder and neck based on individual assessment and progression Exercises progress from maintaining a neutral posture in all positions, to static rotation control in all positions, to dynamic rotation control on a stable base, then on an unstable base with weight as required	Sessions – functional movement-based core conditioning elements	I: Sit-ups II: Not included III: Yes IV: Not included
			Cardiovascular Training			
Under supervision of PTI	I: No II: No III: As per RAF	After ergo tests, pilots got cardiovascular training programme	Bodyweight and weighted exercises Anaerobic crossfit training (workouts) → high intense interval training Bicycle ergometer and running for aerobic training	High-intensity anaerobic-based interval sessions combined with weighted whole-body exercises	High-intensity aerobic training element using resistance trainers – Ergo rower, Aerodyne bike trainer, Ski-Erg, or interval-based running training	I: Running II: Not included III: Running IV: Not included

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
Whole-Body Flexibility and Mobility						
Under supervision of PTI and Physiotherapist, specific spinal and scapular mobility exercises, global mobility and stretching exercises based on individual assessment	I: No II: No III: As per RAF		Individual flexibility and mobility exercises adapted to the need of the pilot and the result of the assessment	Under supervision of PTI, individual flexibility and mobility exercises	Pre- and post-weight training mobility exercises	I: Stretches II: Not included III: Yes IV: Not included
FREQUENCY OF EXERCISES						
2x/week (1x/week with Physiotherapist, 1x/week with PTI) Minimum 9 individual sessions with Physiotherapist Group sessions Fit4Pilot with Physiotherapist or PTI	I: No II: No III: As per RAF	2 – 3x/week	2 – 3x/week	Supervised sessions with PTI and/or Physiotherapist minimum of 2x/week for 12-week period at start of each phase of flying training	4 sessions per week recommended	I: 3 – 4/wk Aerobic II: 3 – 4/wk III: Up to daily IV: Up to daily
PERSONNEL INVOLVED						
Flight Surgeon – responsible for yearly medical check-up, for Air Transport Pilot License / Air Physio Courses	I: Self II: Self III: As per RAF	Flight Surgeon	Flight Surgeon – overall responsibility for HPE	Av Med Physiotherapist has overall responsibility	Program Leads – Aircrew PCIMP Director, Institute of Aviation Medicine (IAM) PCIMP Lead, IAM Human Performance Specialist Physio Lead, Strength and Conditioning PTI Lead	I: Flight Surgeon II: Flight Surgeon III: Contractor Medical Staff IV: Flight Surgeon – can track aircrew

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
PERSONNEL INVOLVED (cont'd)						
Physiotherapist at Military Hospital Queen Astrid responsible for individual assessments Physiotherapist at the air base responsible for information session about neck and back pain Individual follow-up during pilot training		Physiotherapist for FMS and ergo Cooper and strength tests by Chief of Physical Education and Sports	Physiotherapist – responsible for movement screening, available for assessment and treatment as required, supports Sports Scientist with training sessions	Physiotherapist – overall responsibility for ACP, responsible for conducting cervical spine assessment and monitoring of aircrew	Sports Physiotherapists and Exercise Physiologists – contracted staff directly in support of PCIMP at each location Current resourcing factored at 1 Physio and 1 EP per 100 aircrew; smaller bases (i.e., less than 30 aircrew) serviced by 1 Physio only	I: Not involved II: Physical Therapist III: Contractor Physical Therapist IV: Physical Therapist – overall responsibility
PTIs working in air bases – complete 1-day course Fit4Pilot, responsible for supervised sessions Fit4Pilot, cardiovascular and strength training		Physiotherapist and Physical Training Officer for day training programme	Sports Scientist – responsible for day to day training	PTI – complete 5-day ACP Instructors Course, responsible for strength, anaerobic capacity and flexibility assessments, and for supervising all sessions	PTI – 1 PTI assigned to PCIMP at each location at a current ratio of 1 PTI per 100 aircrew, PCIMP PTI staff funded to conduct external civilian S&C qualifications up to minimum Grade 1 S&C Coach, preferably Grade 2	I: Aerospace Operational Physiologist, where available; Flight Surgeon, if work allows II: Aerospace Operational Physiologist III: Contractor Physiologist or Contractor Athletic Trainer IV: Aerospace Operational Physiologist – can track aircrew

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
PERSONNEL INVOLVED (cont'd)						
Embedded Psychologist – Mental Coach, responsible for TOP[2] theoretical and practical group sessions, individual sessions and follow-up	No Psychologist included	No Psychologist included	Flight Psychologist – as required	No Psychologist included	Sports Psychologist – not currently part of programme	No Psychologist included
Expert in nutrition, responsible for information briefing about healthy and sports nutrition and hydration; and advice to improve meals on base and food pack for long-haul flight						
RESULTS OF RESEARCH INVOLVING SPECIFIC PROGRAMME						
		Training intervention decreased in-flight muscle strain in cervical muscles [48] More fit pilots experience less disabilities though they have more MSI pain [49]	Reducing of individual pain symptoms (preventive training) Improving the strength and mobility values in comparison to the previous years	ACP has demonstrated excellent content validation for use with aircrew Significantly reduces heart rate whilst maintaining systemic blood pressure at +5.5 Gz [50] Anecdotal reports from aircrew who have completed supervised ACP indicate reduced neck pain in fast jet aircrew during BFM/ACM and rotary aircrew report less fatigue after 2 hours of NVG flying	Data collection and research will be ongoing throughout the PCIMP model Initial observations indicate early signs of a significant reduction in injury rates, and increased rates of flying	I: None available II: In use at Luke AFB and being studied there III: None available IV: In use USAF-wide and outcome studies planned including at Lakenheath AB, England

[2] TOP: Technique d'Optimisation du Potentiel.

BELGIAN AIR FORCE	CANADIAN FORCES HEALTH SERVICES	FINNISH AIR FORCE	GERMAN AIR FORCE	UK ROYAL AIR FORCE	RAAF	US AIR FORCE
ADDITIONAL COMMENTS						
Implemented thanks to participation in HFM-252 Based on best evidence practice from UK ACP and German HPE	I: Warm-up/cool-down portion only of UK ACP II: Warm-up/cool-down portion only of UK ACP III: Implementation of mandated full UK ACP			Based on previous RAF conditioning programmes and research [51], [52] Impact of ACP on reducing neck pain in all UK military aircrew is planned	A more scientific analysis will be conducted over the next 18 months	I: Initial version written when F-15s, F-16s fielded II: Written by 711HPW and Luke AFB members III: Paid for by State of Oregon Air National Guard IV: Written by senior USAF Physical Therapists and made available to all PTs, FSs, and AOPs USAF-wide

4.3.1.2 Metrics and Data Analyses

1) Conduct of these studies is often hampered by volunteer recruiting challenges to obtain a statistically valid sample size and retain subjects throughout the study. As such, it would benefit all national programmes to be able to use a common set of metrics, such as:

   a) Objective measures: CROM, neck / upper shoulder muscle strength and endurance.

   b) Subjective measures: pain magnitude (e.g., Visual Analogue Scale), persistence, number of incidents, body location; and assessment instruments, i.e., weekly (regular) log, questionnaire (includes core questions in Annex D and any additional nation-specific questions, e.g., concerning new equipment, specific air platform, etc.).

      i) To simplify compliance and data collection, use electronic log access, e.g., Internet, e-mail, smartphone application.

   c) Common analysis approaches for objective and subjective measures.

   d) Common success metrics: Global Rating of Change (GRC), pain (better management, metrics and tracking progress) and/or performance of flight-relevant tasks that neck pain impedes, such as visual target tracking.

      i) GRC questions are designed to quantify a patient's perceived improvement or deterioration over time [53]. Using a 15-point GRC scale, ranging from –7 (a very great deal worse) to 0 (about the same) to +7 (a very great deal better), participants are asked to answer the following question: "Overall, has there been any change in your condition since the initial evaluation? Please indicate if there has been any change in your condition by choosing one of the following options." The validity, reliability (ICC = 0.90) and responsiveness (important improvement +3) of GRC scales have been established [54].

2) Need for low cost and portability: Subjects can perform exercises in a gym and at home – using no or minimal specialized equipment, e.g., resistance bands, own body weight.

3) Progression of exercises:

   a) Initial emphasis on neck / upper shoulder awareness and technique. (Initial emphasis is to train aircrew on doing exercises to recruit/favour the use of deep paravertebral neck muscles, and minimise the use of superficial neck flexors.)

   b) Increasing intensity to build core stability.

4) Impact of national policy: Compliance will depend on whether or not the programme is required or just recommended. For example, Germany and the UK have a requirement but policy prevents establishing a control group.

5) Lessons learned for conducting such a study:

   a) Inclusion criteria and what is disqualifying. For example, subjects must have not had previous neck surgery, neurologic symptoms, serious back pain, participated in neck-training programme during the previous twelve months, or are undergoing neck/shoulder treatment at the time of testing. Subjects with planned extended leave during the intervention period should be excluded.

6) Recruitment:

   a) This is facilitated if squadron management (commander or executive officer) endorse and support participation.

7) Participant compliance and retention:

   a) Aircrew have very busy operational schedules and investigators need to accommodate by making it easy for participants to obtain training. Training sessions should be well organized to avoid wasting time and be as short as practicable. The study must account for participant availability and it may be necessary to offer assistance where appropriate to retain their participation.

   b) Be sensitive to privacy concerns, i.e., hold training away from doors and where they cannot be seen by nonparticipants. Training materials, written and video, should be provided. Explanations should be clear and unambiguous and presented in a friendly manner without being condescending. Participants should be given ample opportunity to react and ask questions.

   c) Expect subjects to drop out, so over-recruit.

   d) Make it easy for participants to submit log updates using electronic means. Discourage participant competition to avoid possible injury or use of exercises by control group.

   e) Investigators must be in regular communication with participants (do not let much time lapse between speaking, even just to confirm that all is still on track, scheduled, etc.). Understand that participants may be reluctant early in the process until they are comfortable with the study procedures.

   f) Provide ongoing feedback to participants and explain their results, e.g., how things are changing, what the different numbers mean, and why you are measuring it, etc.

   g) Be strategic and progressive when making any changes to the plan; participants like to know exactly what they are doing during sessions, and change will often discourage continuation (that includes continuity in the experimenters).

   h) Compensation can help if organizational business rules permit it.

8) What to do if injury occurs:

   a) Establish clear procedures for treatment and determination if the participant can rejoin the study. For example, depending on the severity of the injury, the volunteer should receive medical evaluation and care according to standard practice of care. No volunteer should be denied or receive restricted clinical care as a result of participation in a study. All volunteers should be eligible to receive the full spectrum of standard of medical care for acute pain and/or injuries. Upon resolution (or stabilisation, depending on the nature of the medical issue), the medical officer will evaluate the volunteer and recommend a course of action, either to resume study participation or exit the study. If the volunteer is enrolled in the exercise group and is cleared to resume participation, the exercise sequence may be adjusted to low-load movements and the volunteer monitored until they resume the same pre-injury exercise regimen.

9) How to measure strength/endurance with subjects having pain:

   a) Typical measures of strength and endurance based on maximal voluntary muscular contraction are contraindicated for subjects with pain. Procedures must take this into account and begin with low target levels of exertion.

   b) Measures used to quantify muscle strength/endurance must show good metrological properties, including reliability, validity, and responsiveness.

10) What to do with their data if subjects leave study early:

   a) If a study terminates with the end of the intervention and subjects do not complete the exercise course, their data cannot be used. If subjects are followed, data should be included based on the participation time, e.g., 3, 6, 9, or 12 months.

4.3.1.3 Training the Trainers for Consistency

A common protocol must be followed such that all study personnel train subjects in the same manner and subject performance assessed in the same manner.

4.3.1.4 Participation Challenges

Challenges for national participation include long lead time to initiate programme for ethics approval, funding, operational approvals, recruitment, and subject compliance. There may be a perception from air forces that while the need is established, the desire is to implement a quicker solution without rigorous scientific validity.

4.3.2 Collaborative Multinational Study Requirements

Based on the collective experience of the RTG, recruiting and retaining sufficient exercise study volunteers to achieve statistically significant results is a challenge. To address this, the use of collaborative studies to conduct a multi-organization exercise study can be undertaken. It is suggested that the following be adopted to improve the chances of success:

a) Intervention is based on a common regimen, e.g., Randomized Clinical Trial (RCT). An example of an RCT regimen for helicopter aircrew can be found in Ref. [51].

b) Intent is to add an average of 2 – 3 exercises to a participant's regular routine.

c) Requires multi-nation participation in order to obtain sufficient number of subjects for statistical power.

d) Establish baseline metrics.

e) Establish common initial intervention period during which volunteers must be available for (e.g., eight weeks).

f) Check progress using weekly logs that require less than five minutes to complete.

g) Objective measures taken at 3, 6, and 12 months post-intervention.

h) Ideally, establish single source for randomization.

i) Develop national table of participants, timelines, sample size, flight billets / roles / aircraft type (rotary-wing, fighter, attack); pilot, crew, instructor pilot, novice to expert).

j) Subject pool: include subjects with and without pain; control group, randomized group composition; requires subject availability for intervention period and retest; accommodate deployment and flight schedules.

4.4 WORK-REST CYCLES

It is well known that inadequate rest to allow for recovery after physical exertion can lead to reduced muscle capacity and an increase in injury risk. Recently, a study was conducted to determine the parameters for the optimal balance between operational work and rest scheduling [55].

After obtaining approval from the Defence Research and Development (DRDC) Health Research Ethics Committee, interviews were conducted with 128 Canadian Griffon pilots and Flight Engineers. After basic demographic information was collected, participants noted whether or not they were chronic or non-chronic pain sufferers. If a participant stated that their neck trouble does not completely subside after a flight and they always have some form of trouble for at least six months at a time, the study classified this participant to be a "chronic" pain sufferer. If a participant's neck trouble vanished, then the participant was deemed a "non-chronic" neck pain sufferer. Participants were also asked if they suffer neck pain during a typical day or night Tactical Helicopter Mission (THM), at what point during the mission the pain occurred, and the length of time (in hours) that the pain persisted.

Participants were also asked to rate their pain intensity on a VAS anchored at "no pain at all" to "worst pain imaginable." Chronic sufferers were asked to rate their baseline level of pain, as well as the pain levels during/after a typical day or night mission. Non-chronic sufferers were only asked to rate their pain if they suffer pain during a typical day/night THM. Table 4-4 summarises the number of participants with neck trouble and those that are chronic. A typical day or night THM lasts about 2 hours and involves different tasks and postural sequences [56].

Table 4-4: Number of Participants with (a) No Neck Trouble, (b) Occasional or Episodic Neck Trouble, and (c) Chronic Neck Trouble. (FE = Flight Engineer).

	Number of Participants Interviewed	No Neck Trouble	Non-Chronic Neck Trouble	Chronic Neck Trouble
Pilot	91	19 (out of 91)	72 (out of 91)	19 (out of 72)
FE	37	6 (out of 37)	31 (out of 37)	12 (out of 31)
Total	128	25 (out of 128)	103 (out of 128)	31 (out of 103)

Persistence time was defined as the time in hours for the neck pain to vanish after a THM, or for chronic sufferers, the time for the neck pain to go back to the chronic baseline level. Of the 53 participants that have neck pain during a day THM, the mean (±SD) persistence time was 31±38 hours. For the night THM, the persistence time mean was 34±38 hours. Once outliers were removed (participants with persistence times of less than 8 hours and more than 100 hours) the persistence time mean for day THM becomes 28±17 hours and for night THM 33±23 hours as summarised in Table 4-5.

Table 4-5: Persistence Times for a Typical Helicopter Day and Night Mission.

	Neck Trouble – Day THM	Neck Trouble – Night THM	No Trouble During THM, But Still Has Neck Trouble
Number of Participants	53	92	11
Mean Persistence Time (hr)	28±17	33±23	N/A

Similar studies have been conducted amongst professional athletes [57]. In one study, heart rate variability was used to measure the rest and recovery time of thirty-one Finnish hockey players. The average time players started to recover after a game was 7.7 hours, while the average duration for full recovery was 5.6 hours. Note that there were significant individual differences with respect to recovery duration (i.e., the fastest recovery was 2 hours immediately after the game, and the slowest did not recover at all during the night. The sum of the average start time and recovery duration (somewhat equivalent to the previous "persistence time") is 14.3 hours.

Sports medicine and intervention strategies may help reduce the need to rest neck muscles. For example, a simple intervention strategy, such as a coach making assessments about whether a player is ready to play based on the coach's experience and intuition as well as a conversation with the player, may be applied to aircrew. More objective measures are being explored, such as the use of physiological monitoring technologies where patterns may be noted after several sorties, and these data may be used in conjunction with other information to determine 'fit for flight'.

We recognise that extended rest as recommended by research and sports medicine may not be operationally feasible. However, when operations allow, we recommend that aircrew be allowed time to rest so that muscles can recover. In particular, work needs to be done to quantify the relationship between time of rest and quality of rest to develop an optimal balance between operational and physiological requirements. For example, while the mandatory 12-hour rest before a mission may be sufficient for cognitive recovery, depending on the non-flying activity performed, this may be insufficient for muscle recovery. Therefore, it is recommended that aircrew take the opportunity to rest their muscles whenever possible.

4.5 TREATMENT

4.5.1 Overview

The goal of the treatment is to have a pilot that is fit to fly as soon as possible but without compromising safety or the recovery of the injury. Since some aircrew neck pain is caused by sudden trauma, such as muscle strains or sprains, neck pain treatment generally begins with conservative care, i.e., patient education and control of pain and inflammation [58].

An integrated multidisciplinary approach gives a patient the best chance at improving via the involvement of multiple caregivers with multiple modalities. Aircrew need particular attention because of their 24/7 National Security duty schedules and their need to perform at peak levels whenever they are on shift. Due to these expectations, the following approach can be suggested:

- For acute problems, initial intervention should occur on the same calendar day or, at latest, the next calendar day (this requires a 24/7 on-call schedule for a Physiotherapist (PT), or similar member, just like the FSs maintain).
- Medical staff seeing aircrew should have special training in aerospace medicine.
- PTs, and other staff if feasible, need to deploy with the unit, just as the Flight Surgeon (FS) does.

4.5.2 "Red Flags" in Patients with Neck Pain

The most common examination findings in patients with acute neck problems are unilateral pain, limited and painful neck movements, and muscle spasm. The outcome of these injuries is favourable in up to 90% of patients following conservative treatment [59], [60], [61], especially when treated early and properly. Nevertheless, a thorough history and physical examination are necessary to identify "red flags," such as trauma; radiculopathy/myelopathy; infection or malignancy; pain that is increasing, is unremitting or disturbs sleep; severe limitation during neck active range of motion; severe tenderness over one vertebrae; or history of tuberculosis, Human Immunodeficiency Virus, cancer, inflammatory arthritis or prolonged use of corticosteroids that need immediate further action by the flight surgeon [62]. Imaging is not required unless there is a finding of one of these "red flags."

An accurate history should always initially exclude a traumatic injury caused by a blow to the head or neck as a possible cause for the problems. If the patient reports an acute trauma, or if there is uncertainty, radiological evaluation is necessary before starting a treatment besides a pain medication.

If the patient states that there is no trauma, the next action is to check if the patient suffers from a disease process marked by nerve compression [63]. This impingement typically produces neck and radiating arm pain, weakness or numbness, sensory deficits, reflex deficits and/or motor dysfunction in the neck and in most of the cases in the equilateral upper extremity. MRI or Computerised Tomography (CT) should be used to confirm the diagnosis before any form of manipulation or mobilisation is performed.

An occasionally more difficult diagnosis in patients with neck pain is an infection or a malignancy [64]. While it is pretty obvious when neck pain is accompanied by fever, a progressive numbness or sensory deficit or even a severe hypotension indicates the need for an immediate further examination. Unfortunately, in many cases, especially in patients with an osteomyelitis or a malignancy, the symptoms are very unspecific and sometimes many months elapse until the right diagnosis is made. Signs that divide infections and malignancies from muscular problems that are typical for pilots are that if you apply a mild traction, patients with muscle-related injuries usually feel relief. In case this mild traction worsens the symptoms or if the symptoms are unchanged after two weeks of therapy or get worse during therapy, you need to be very careful and further examination is necessary. In most cases MRI is the gold standard to exclude an infection or malignancy.

Having excluded these “red flags,” there is usually a multimodal approach to the treatment of neck pain beside the most likely already started, i.e., pain medication including from this point on, manipulation or mobilisation, active exercise, or soft tissue techniques. What kind of treatment is the best for the patient depends on the knowledge and possibilities of the treating clinicians and the available facilities.

4.5.3 Acute Period Intervention (Time of Injury to 1 Week Post-Injury)

Patient education is critical for a realistic expectation of resolution of symptoms. This needs to be integrated into each phase of the treatment process. Refer to Section 4.2 for specific areas to cover in education for patient. This section provides guidance from the time of injury to 1-week post-injury phase.

4.5.3.1 Conservative Measures

Flight-related neck pain can lead to impaired operational performance, reduced medical category, and possible long-term degenerative injury. Aircrew are often reticent to report neck pain and musculoskeletal injuries for a variety of reasons, including lack of confidence in the availability of aeromedical understanding within physiotherapy departments, especially if the PT is not a part of the aeromedical team, fear of grounding, and long delays due to the referral process.

One approach instituted by some air forces is to have an Aircrew Direct Access Physiotherapy Service or embedded PTs in the Squadrons that offer the opportunity to empower aircrew to self-care and self-manage to meet their individual needs. The goal of this service is for flight-related neck and back pain treatment to become a recognised part of aircrew culture, and is provided by an Aviation Specialist Physiotherapist (ASP).

It is expected that ASPs have advanced musculoskeletal expertise with thorough knowledge and understanding of Aviation Medicine. These qualifications enable the ASP to work independently with aircrew and perform detailed assessments in order to formulate specialist, individual treatment and rehabilitation programmes.

Success of an ASP programme relies on good lines of communication with the FS, the Officer Commanding of the Flying Squadrons, and the pilots. Management of expectations of all stakeholders is vital.

Aircrew should be seen in a designated treatment room/area within the squadron buildings or within the Primary Care Rehabilitation Facility. Weekly meetings are conducted with the FS and all Physiotherapists, enabling discussion of all patients.

To be consistent with this programme, an ASP should deploy with their Squadron to Exercises and Operations in order to enable treatment/management of any flight-related injuries whilst still in the acute/sub-acute stage [40]. During deployment pilots have more time to take care of their "body" as the pressure to go home is taken away, which also provides an opportunity to nurture a trust relationship between the ASP and their pilots.

The model currently being discussed in the US Air Force would have aircrew, with minimal to mild cases of neck pain, go directly to their PT and/or Athletic Trainer without Flight Surgeon involvement or grounding. Often, such episodes resolve in hours. Since pilots do have input into their flying schedule, the pilot would adjust his/her schedule so that his/her next flight would occur when he/she was free of symptoms. In this scenario, the pilot is in the "driver's seat" of the process. Obviously, for other scenarios of neck pain, including those that are not mild or those that have concerning signs detected by the PT, the pilot will see the Flight Surgeon, and grounding for some period of time may occur. Note that prior to any intervention which utilises movement or pressure such as soft tissue techniques, mobilisation/manipulation, or exercise, one must be sure the member has no pathology that the intervention could make worse.

4.5.3.1.1 Interventions

Ice: Usually used immediately, as well as anytime. This can be used to reduce acute oedema by causing vasoconstriction of inflamed or injured vessels which leak fluid. It can also reduce the sensation of pain via a numbing effect or a distracting effect (the cold surface sensation taking the patient's focus off a deeper site that is a source of pain).

Heat: This can be used after the period of oedema; if used during the oedema phase it can worsen oedema by causing vasodilation of leaky vessels resulting in a higher volume of leakage per unit of time. In the post-oedema phase, vasodilation via heat can result in faster healing via delivering an increased amount of oxygen and materials needed for healing to occur.

Analgesics (Non-Narcotic): An example in this class of medications would be acetaminophen and other non-prescription pain relievers that are aeromedically approved by that pilot's nation. It is essential that there is no drowsiness associated with these drugs so they are safe for driving, work, etc.

Non-Steroidal Anti-Inflammatory Drugs (NSAIDs): An example in this class would be aspirin, ibuprofen, and naproxen and others if aeromedically approved by that pilot's nation. The aim of these medications is to reduce inflammation, which should promote resolution of painful sites of inflammation. They have an analgesic effect as well. Usually there is no drowsiness associated with these drugs so they are safe for driving, work, etc. Some patients may need ulcer and acetylsalicylic acid precautions for some of the NSAID types. According to a systematic review of NSAIDS for spine pain, there was no significant difference in efficacy between different NSAID types, including selective vs. non-selective NSAIDs [65].

Muscle Relaxers: An example in this class would be cyclobenzaprine and diazepam. The aim of these medications is to relax muscles that may be somewhat contracted due to inflammation. They sometimes have an analgesic effect. If they are used, most will cause drowsiness so they cannot be used while driving, at work, etc. They are often used to reduce pain at night so that the patient can sleep. In the case of an aviator, these could only be used while the flyer is grounded. Results of a review of RCTs in spine pain showed that there is strong evidence that any of these muscle relaxants are more effective than placebo. The various muscle relaxants were found to be similar in performance [66].

Oral Steroids: Steroids have anti-inflammatory effects which should promote resolution of painful sites of inflammation. Such sites could include the joint surfaces between vertebral bones as well as neural surfaces that have become inflamed by contact with elements of bone. They have been used to improve or resolve signs and symptoms from spinal nerve impingement. Steroids can break the cycle of friction on nerve by bone or disc causes nerve swelling, then there is more friction on nerve from its now swollen larger size, repeat the cycle, etc. Steroids can reduce the diameter of the nerve by reducing inflammation, sometimes to the point of no remaining contact with the surfaces causing the original condition. A recent study in spine pain patients confirmed their benefit. Patients treated with a single dose of dexamethasone had significantly greater reduction in pain at 24 h than placebo and significantly shorter emergency room stay: median: 3.5 h vs. 18.8 h [67]. And in patients who had neck pain with cervical radiculopathy for at least one month, a 10-day course of oral steroids resulted in a significant reduction of pain compared to placebo [68]. Depending on the individual nation's aeromedical policy, use may require temporary grounding until usage ceases.

Analgesics (Narcotic): Physiological tolerance over time causes the need for larger and larger doses of a narcotic pain reliever in order to achieve the same amount of pain relief. Due to tolerance, and the potential for damage to organs such as the liver, as well as their addictive potential, many practitioners will not prescribe narcotics for pain relief unless a known endpoint for their use exists (such as in a post-surgical patient whose pain will diminish rapidly as the surgical site heals). If they are used, most will cause drowsiness so they cannot be used while driving, at work, etc. They sometimes are used to reduce pain at night so that the patient can sleep. In the case of an aviator, these could only be used while the flyer is grounded.

4.5.3.1.2 Physiotherapy

Spinal Manipulation and/or Mobilisation: For sub-acute/chronic neck pain, a single manipulation may produce temporary pain relief. At short-term and intermediate-term follow-up, multiple sessions of thoracic manipulation are favoured for pain reduction among participants with acute/sub-acute neck pain, and for functional improvement among those with acute to chronic neck pain. Cervical manipulation has produced changes in pain, function, quality of life, global perceived effect, and patient satisfaction that are comparable with those attained with cervical mobilisation up to intermediate-term follow-up for patients with neck pain of any duration. Gross, Langevin, et al. (2015) have shown that cervical manipulation for acute/sub-acute neck pain was more effective than varied combinations of analgesics, muscle relaxants, and non-steroidal anti-inflammatory drugs for improving pain and function at up to long-term follow-up. For acute neck pain, cervical manipulation may be more effective than thoracic manipulation in improving pain and function up to intermediate-term follow-up [69].

Soft Tissue Techniques: Soft tissue manipulation techniques have been described as safe for the management of mechanical neck pain, and any side effects were temporary and benign [70].

Needle Procedures: Procedures can include local anaesthetic, saline, or dry needling of trigger points as well as acupuncture. If a local anaesthetic like lidocaine is used, there can be useful diagnostic information collected since there is immediate, although temporary, pain relief from the local anaesthetic. These procedures can be used with new onset neck pain as well as an acute episode of neck pain in someone who has chronic episodic neck pain. Individuals with chronic neck pain who received acupuncture reported better pain relief and improvement in disability in the short term than those who were on a wait-list or had sham treatments; treatments appear to be safe, and investigators have reported only minor and short-lasting side effects [71]. Of note are the results of an evaluation of fifty-seven systematic reviews of acupuncture as a treatment of pain from a variety of causes that were mixed at best except for the unanimously positive conclusions from more than one high-quality systematic review for neck pain [72].

Electrotherapy: Transcutaneous Electrical Nerve Stimulation (TENS) is the most commonly used form of this intervention; it is so safe as to be available over the counter in many nations. Some patients have claimed improvement in their spine pain from this intervention although improvement may be confined to when the unit is turned on. A recent Cochran review stated that for patients with acute neck pain, TENS possibly relieved pain better than electrical muscle stimulation, not as well as exercise and infrared light, and as well as manual therapy and ultrasound [73].

Exercises: Exercise is safe, with temporary and benign side effects. There appears to be a role for strengthening exercises in the treatment of chronic neck pain, cervicogenic headache and cervical radiculopathy if these exercises are focused on the neck, shoulder, and shoulder blade region. Furthermore, the use of strengthening exercises, combined with endurance or stretching exercises has also been shown to be beneficial. There appears to be minimal effect on neck pain and function when only stretching or endurance type exercises are used for the neck, shoulder, and shoulder blade region [74].

Neck Traction: Recently, a neck traction study was concluded at a USAF F-15 base [75]. The procedure was to evaluate a small pneumatic portable traction device: approximately 10 lbs and about the size of a shoebox, with no cables or weights and therefore useable in deployed aviation settings. Use of the device for six weeks, three times per week for ten minutes (after flight if a flying day) resulted in a significant reduction in pain for pilots with noticeable initial daily pain ($p = 0.025$), and in post-flight pain in these pilots ($p = 0.013$).

Functional Check: Aircrew returning to flying duties after neck injury or with recognised neck restrictions should have formal assessment of their capability in role. The assessment should be conducted by suitably qualified and experienced persons, e.g., Senior Operator/Instructor. The outcome of the assessment should be recorded within the aircrew flying records and on the Medical Information System. Aircrew should be reviewed after one month or ten hours flying, whichever occurs first. See Annex G for steps to follow to check neck function for fast jet and rotary-wing aircrew.

4.5.4 Sub-Acute Period Intervention (1 Week to 3 Months Post-Injury)

The options for this phase of 1 week to 3 months post-injury are in addition to those listed for the acute phase.

Injection of Substances Other Than Anaesthetics, Saline, or Steroids: Although a spine pain review stated there is no strong evidence for or against the use of any type of injection therapy, it also stated that it cannot be ruled out that specific subgroups of patients may respond to a specific type of injection therapy [76].

Anti-Depressant Medications: In some patients, these have resulted in lowering the overall average pain level, although they have no action on resolving any pathology causing the signs and symptoms. A review of this intervention on spine pain stated that although there is no clear evidence that antidepressants are more effective than placebo in the management of patients with chronic low back pain, there is evidence for their use in other forms of chronic pain [77]. Note that depending on the nation and agency, this may require temporary grounding until usage ceases.

Yoga/Pilates/Similar Exercise: In some patients, beneficial effects are similar to those from manipulation – improved signs and symptoms. Often it is not tried until after the acute phase is over. Evidence in a review of three randomized controlled trials at a significant level of benefit ($p < 0.001$) was found for short-term effects on neck pain intensity and neck pain-related disability suggesting that yoga might be a good treatment option [78]. Evidence in another review of three RCTs showed improvements in chronic neck pain intensity ($p < 0.05$ in two trials, $p < 0.001$ in one trial) and functional disability ($p < 0.05$ in two trials, $p < 0.001$ in one trial) compared to a control group [79].

4.5.5 Chronic Period Intervention (Greater than 3 Months from Injury)

The options for this phase of greater than 3 months from injury are in addition to those listed for acute and sub-acute phases.

Chronic neck pain may induce negative changes during daily activities [80], but also work-related activities [81]. The multidimensionality of chronic neck pain, referring to pain mechanisms and psychosocial factors interacting with the body functions and structures of people, the activities people do and the life areas in which they participate, is fully accepted [82], [83]. Moreover, the bio-psychosocial model is implemented increasingly in diagnostics and the treatment of patients with neck pain in the general population [83]. Therefore, a multidisciplinary approach should certainly be encouraged for aircrew suffering from chronic neck pain.

Red flags have already been discussed in Section 4.5.1, but ‘Yellow’ flags should be considered if you are treating patients with chronic neck pain. Yellow flags are best conceptualised as barriers to recovery and have shown to be indicative of long-term chronicity and disability [84]. As mentioned before, the physiotherapist should take the aircrew’s history thoroughly and based on the bio-psychosocial model.

A visual inspection of the pilot should be done to detect bad postures whilst sitting and standing. An extensive clinical assessment based on the planetary model [82], an adapted model of the International Classification of Functioning, Disability, and Health, is necessary to improve the management of the pilot’s treatment and accelerate the return to normal function and flight operations.

This clinical assessment should include active and passive range of motion of the cervical spine, cervical proprioception and motor control, palpation of trigger and tender points in the neck-shoulder region, neck muscle strength and endurance, and provocation tests. Given the neck neuroanatomical interconnections and neurophysiological relationships with shoulders, thoracic spine, and temporomandibular region, a clinical assessment of these regions is also useful.

Based on the findings of the pilot’s history and clinical assessment, and taking into account the presence of possible psychosocial factors, an individualized treatment can be started to restore articular, myofascial, neurogenic, and sensorimotor control function, and so recover normal movement function which will lead to return to normal professional, sports, and social activities.

In case of predominant psychosocial factors (e.g., stress, familial conflicts), the pilot should be referred for follow-up to the psychologist or mental coach of the base as underestimation of these factors may have a significant influence on the therapeutic results.

If a pilot presents neurologic signs, a neurologic examination is necessary, including nerve palpation, skin sensitivity, motor function (manual muscle testing, reflexes), and an Upper Limb Neurodynamic Tension Test. If lower or upper motor neuron signs are noticed, such as muscle weakness, hyporeflexia, or atrophy, the pilot should be referred to the base flight surgeon or neurologist for further examination.

In case of chronic neck pain that has no major pathology or neurological signs, there is strong evidence that a therapeutic intervention including active exercises would be beneficial to decrease pain and increase functionality [85], [86]. They should include a combination of stabilisation/strengthening, endurance, and stretching exercises for the cervical spine, shoulders and scapulothoracic region [74], [87], [88]. Resistance exercises to increase isometric strength of the deep cervical flexors have proved to ensure correct muscle recruitment and function [89].

The main beneficial frequency of exercise to target pain and weakness in a population with chronic neck pain is three times a week and education should be incorporated as part of a multimodal approach. An exercise session duration between thirty and sixty minutes produces the best results and the exercise intervention should last at least between six and twelve weeks for physiological benefits to occur. Pilots should be encouraged to continue life-long exercise to maintain long-term benefits. The training intensity varies depending on the type of exercise resistance or endurance and should be individually tailored based on baseline abilities as defined by the pilot's MVC values [88]. MVC can be measured during the initial strength assessment using a variety of devices (David Back, MCU, manual load cell: see Section 4.2.4, Assessment section in Summary of Active Conditioning Programmes Deployed in NATO Nations).

In the case in which pilots are already in the chronic phase at the time of first treatment, manual therapies, including joint mobilisation, manipulation, Sustained Natural Apophyseal Glides exercises could be added [63], [74], [90], [91], [92]. The combination of these passive treatments with active therapy, including stabilisation and strengthening exercises for the cervical spine, shoulders, and scapularthoracic region, is more effective than passive treatments alone and is necessary to increase the long-term effects of the therapeutic interventions [74], [93], [94].

Other therapies, such as breathing exercises, general fitness training, proprioceptive exercises (balancing and perturbation exercises, joint repositioning), and acupuncture, could be suggested for the treatment of chronic mechanical neck disorders [74], [95]. There is a lack of evidence regarding the use of massage therapy as a therapeutic intervention in patients with chronic neck pain [70].

Although some patients have had improvement in symptoms with the modalities of ultrasound, diathermy, and some forms of electrotherapy, several studies failed to show the expected level of statistical significance for short-term, long-term, or functional improvement in chronic neck pain [63], [73], [91].

Biofeedback: The term biofeedback can be used to describe when a patient uses electromyography output to strength train certain muscles such as the deep cervical flexors – in which case it is covered under the topic of neck strengthening. When biofeedback was used to strength train deep cervical flexors, that group had significantly less pain and disability than the group that did not use the biofeedback [96]. Also, via biofeedback some patients can learn to lower their pain levels by learning to relax regions of their body or by learning to focus their attention away from the pain. Even though some individuals can effectively use these biofeedback techniques, some studies have not shown this to be true for groups of patients in RCTs. When a study of neck pain subjects used ergonomic intervention with or without biofeedback, there was a significant reduction in pain intensity and disability in both groups but there was no significant difference between the two groups [97].

Invasive Electrical Stimulation: Similar to TENS, there are some accounts of symptom improvement in patients who have had electrodes implanted under the skin, sometimes deep in proximity to sites of pain. This intervention will not be discussed since malfunction of the power source would allow unpredictable return of pain, and it would not be considered for waiver approval to fly.

Pain Threshold Modification: In patients who can tolerate activity, various regular activity may raise one's pain threshold – and therefore reduce their pain level. Popular activities include swimming, pool exercises, and recumbent cycling. An analysis found the average effect size to range from moderate to large in healthy adults depending on pain induction method and exercise protocol. Importantly, all three types of exercise: isometric, aerobic, and dynamic resistance are capable of producing large effects in healthy adults [98].

4.5.6 Surgical Interventions

As documented earlier in this publication, the majority of high-G aviators will experience neck pain at some point in their career. Some of these aviators will experience radicular neck pain – pain that radiates down an arm. One of the causes of such radiculopathy can be a Cervical Radicular Syndrome (CRS) caused by a herniated intervertebral disc [99] This is not just an occurrence in fast jet pilots, it also occurs in helicopter aircrew [32], [100]. In the majority of patients, the symptoms gradually diminish with conservative care over weeks to months. Surgery of a CRS is in most cases the last resort when:

1) Conservative treatment fails; or
2) Unbearable radicular pain persists; or
3) A significant motor or sensory deficit occurs.

Nevertheless, many controversies still exist regarding the timing of diagnostic procedures, the timing of referral of patients to the neurologist or surgeon, and the timing of a surgical intervention for a CRS [101].

Especially in aviation medicine, due to high-G loads in fighter jets and strong vibrations in helicopter flying, cervical spine surgery sometimes occurs towards the end of a flying career. Even if the regulations in the pilot's country include the possibility of a waiver for these cases, some air forces do not grant a waiver for aircrew because of the described high load on the neck by G forces or vibrations during flying. So, it is not a question of surgical technique, instrumentation, or implants (this depends on the different knowledge and possibilities of the chosen hospital); it is a question whether surgery is needed or not.

For many years the traditional surgical method of Anterior Cervical Discectomy and Fusion (ACDF), whether with an autologous iliac crest bone or a cage, had been the gold standard. However, it comes with the disadvantages of motion loss at the operated level and accelerated adjacent level disc degeneration. However, this procedure has been established as a safe intervention and reduces the symptoms in about 90% of the cases [102], [103], [104], [105], [106].

The described problems coming with ACDF (loss of motion and biomechanical impact of the fusion on the adjacent segments) in young patients who have no spinal cord injury, fracture, or instability led to a paradigm shift in the last decade. Cervical arthroplasty is a viable alternative for these patients [107], [108]. New studies show that there may be a small advantage for this kind of treatment independent of the system used [109].

Other surgical procedures, such as the endoscopic assisted micro-decompression [110] or the renewed technique of a dorsal foraminotomy [111], are only relevant for small populations in some specialized hospitals and they do not improve the results in the RTG's assessment.

Nevertheless, even a good result with no neurological deficit and no pain at all after any kind of surgery, may not qualify for flying fast jets or helicopters in some countries. Having this in mind, new ways of prophylactic measures should be taken seriously to protect aircrew from neck problems due to the fact that modern aircraft maximize the level of strain on the neck.

4.5.7 Dental Causes of Neck Pain

The comorbidity of dysfunctions in the stomatognathic system and the pain syndrome in the cervical spine has often been reported [112].

Numerous scientific reports confirm that many researchers have embarked on the examination of the impact of disorders in the "upper quarter" on body posture and pain experienced in various areas of the body but the focus has been mainly to prove the presence or absence of dependence between dysfunction of the stomatognathic system and pain in the cervical spine.

Temporomandibular Disorders (TMD) is a collective term which refers to a large number of clinical problems that involve the masticatory musculature, Temporomandibular Joint (TMJ), or both and the associated structures [113].

TMD aetiology is multifactorial. It may be related to an imbalance among occlusal, anatomical, psychological, and neuromuscular factors, providing neck and head structural dysfunction [114].

The causes of these diseases/symptoms are numerous and include trauma, systemic, iatrogenic, occlusal, and mental health disorders. The neuromuscular system responsible for chewing function has a high potential to adapt to changing conditions. Only when the compensatory capabilities of the masticatory and the neuromuscular system are overstretched dysfunction occurs resulting in clinical symptoms and manifests as pain, severe clicking, or limited mobility of the mandible, forcing the patient to seek help.

Since the TMJ is directly related to the cervical and the scapular region by an interrelated neuromuscular system (through the trigeminocervical nucleus), changes in the cervical spine can cause TMJ disorders and the opposite is also true.

The pain may radiate to different regions, such as the dental arches, ears, temples, forehead, occiput, cervical region of spine, or shoulder girdle [115], [116], but it is mostly frequent in the neck where the lateral support imbalance leads to the bending of the neck to the affected side [117]. Presence of neck pain was shown to be associated with TMD 70% of the time [118].

Furthermore, TMD patients were found to have significantly more asymptomatic dysfunctions of the vertebral joints and increased muscle tenderness than in non TMD patient group. The difference between patients and non-patients for vertebral joint dysfunction and muscle tenderness was greatest in the upper cervical spine [119], [120].

Silveira, Gadotti, Armijo-Olivo, Biasotto-Gonzalez, and Magee [121], found that the higher the level of muscle tenderness in upper trapezius and temporalis muscles is, the higher the level of jaw and neck dysfunction the subject will have.

Since head and cervical muscles are closely related to the stomatognathic system, studies have been carried out to confirm that postural changes of the head and the body could have an adverse biomechanical effect on the TMJ and lead to TMD [122], [123].

The head position seems to affect the position of the mandible. Furthermore, the masticatory muscles that are related to the neck and trunk can also be affected. These muscles are susceptible to suffer the direct influence of the force of gravity. Changes in the head posture in the sagittal plane result in alterations in the pattern of habitual mouth closing and also in the patient ability to reach the intercuspation position. Gonzalez and Manns [124] showed that the anterior head position is accompanied by changes in mandible positioning, with a decrease of the physiological space, which occurs as a result of the displacement of the mandible upwards and backwards due to excessive contraction of the masticatory muscles.

The neck muscles are essential to maintain the balance of the head and the muscles of the stomatognathic system, which could be seen as a coordinated system, in which an intervention at any level could result in changes in this complex. The additional compensation mechanism attributed to the cervical region after an anterior posture of the head can alter the masticatory system and, therefore, the patients become more susceptible to stress, pain and muscular spasms. The abnormal head position refers to the most common manner of bad posture and is the cause of many painful myofascial disorders.

The treatment of TMD is complicated and requires specific knowledge and exercises to strengthen some groups of muscles and weaken others, occlusal splint therapy, massage and pharmacotherapy. Although the treatment seems difficult, most of the patients searching for help due to TMD assess that the treatment is successful, although an accurate diagnosis needs to be made to start the proper protocol of treatment [125], [126].

To achieve the proper relation of the jaw, centric relation should be restored. It is easily performed by occlusal splints. An occlusal appliance is any removable artificial occlusal surface used for diagnosis or therapy affecting the relationship of the mandible to the maxillae. Occlusal appliances may be used for occlusal stabilisation, for the treatment of temporomandibular disorders, or for the prevention of dentition wear. Occlusal splints are used in a vast majority of patients with TMDs to restore the static and dynamic symmetry of the stomatognathic system. Most commonly, they are used in cases with disc displacement. The splints are fabricated individually by an experienced team consisting of a dentist and technician. In case of TMD, there are often large discrepancies between therapists concerning type of occlusal splint most appropriate to use. Many types of splints can be distinguished, for example, stabilisation splint, repositioning splint, relaxation splint, or splints only for protecting oral tissues. Sagittal Vertical Extrusion Device (SVED) splint, which is a typical relaxing appliance, is used because of its influence on jaw muscles.

Walczynska-Dragon and Baron [115] have proven that occlusal splint therapy using the SVED appliance decreases not only aches in the head and all parts of the spine but also disc displacements within three weeks of treatment. The next decrease in frequency of unwanted, unfavourable symptoms was observed after three months of treatment with splints.

Research performed by Lee et al. [127] in a group of 59 patients with somatic TMJ dysfunction showed that intraoral appliance could improve cervical spine alignment and alleviate symptom severity.

Walczynska-Dragon, Baron, Nitecka-Buchta, and Tkacz [128], compared two randomized groups not different regarding age and sex, both consisted of thirty people with TMD, cervical spine pain, and limited cervical spine ROM. Results showed considerable ROM improvement in the cervical spine and the elimination of cervical spine pain felt there by the subjects in the experimental group.

Only a few studies have been conducted on flight pilots. Due to the stresses of flight, military pilots are more likely to experience oral parafunctions, such as bruxism, when compared to the general population. Further, their craniocervical mandibular system is subjected to particular stresses in the course of their duties. A significant percentage (69%) of Israeli air force pilots analysed was affected by bruxism, suggesting the utility of a protective treatment for the teeth [129]. A 32-year-old pilot from the Italian Air Force National Aerobatic Team (PAN) Frecce Tricolori was undergoing gnatho-postural treatment in order to protect the masticatory system and achieve better occlusal balance. A resin stabilisation splint was designed for the pilot's lower arch, allowing for the unobstructed excursive glides of the mandible in the protrusive position, and laterality and occlusal balance in the centric position. This clinical gnatho-postural treatment was able to protect the masticatory system from dental abrasion and improve the pilot's posture control system [130].

4.6 AEROMEDICAL DISPOSITION

4.6.1 Aeromedical Disposition as a Force Enabler

Aeromedical disposition is arguably the most important piece of information that a health care practitioner can provide to the chain of command. The status (size and capability) of the fighting force is a critical consideration for any commander and aeromedical disposition is an important component of that status. As previously described in Chapter 2 of this report, many aircrews with significant neck injuries are limited in their ability to carry out their mission and/or are no longer able to fly at all. By providing the chain of command with clear Medical Employment Limitations (MELs) and associated direction regarding the aeromedical disposition of each member of that fighting force, the aviation health care provider is enabling the commander to make informed decisions.

4.6.2 Aeromedical Considerations

A history of neck pain is an aeromedical concern primarily due to the increased risk of mission capacity compromise and the potential for acceleration of underlying spinal degenerative processes. Pain may be considered from the standpoint of its particular sequelae, which include (in roughly ascending order of severity): worry, distraction, functional impairment, operational flight availability (ranging from time off for medical assessment/intervention to short-term grounding to temporary and permanent change in flight status), and long-term disability (sometimes with compensation implications). As severity progresses, pain may not only impact performance in flight, but activities of daily living as well. Of note, the symptoms and resulting performance deficits may be synergistic (e.g., sleep loss can result in performance decrement during flight duty).

Performance decrements may arise from:

1) Distraction associated with pain;
2) Functional deficits; and/or
3) The effects of the medications commonly used to treat the condition.

If symptoms become incapacitating, there are several possible outcomes of aeromedical concern, including risks to:

1) Mission completion (either current or successive);
2) Individual welfare; and/or
3) Loss of trained resources through attrition.

Given the extensive time and funding required to train aircrew as operational assets, every effort should be made to enable aircrew to fly as long as possible, while remaining within a safe operating window. Generally speaking, continued active flying status in aircrew with neck pain should only be considered when pain is not significantly distracting and there is no significant limitation of motion, loss of strength, or functional impairment that may compromise safe operation of the aircraft, and/or safe egress [131].

4.6.3 Specific Diagnoses with Aeromedical Implications

Given that neck pain is a symptom (not a diagnosis), a thorough review of the clinical history and focused clinical examination are critical for determining the aetiology of the pain, as these will have different aeromedical considerations. The majority of neck pain in aircrew can be attributed to a repetitive strain injury, which in most cases remains relatively uncomplicated. However, there is a relatively small subset of this population who will have pre-existing or underlying (or may progress to) pathology ('organic cause') which may be contributing to the clinical picture. This must be identified as soon as possible, as these will require additional work-up and will have additional aeromedical implications. These conditions include (but are not limited to):

1) Acute Disc Herniation;
2) Abnormal Spinal Curvature (excessive kyphosis, scoliosis and/or lordosis);
3) Ankylosing Spondylitis;
4) Facet Syndrome;
5) Spinal Fractures;
6) Spinal Fusion;
7) Spinal Stenosis; and
8) Spondylolisthesis/Spondylolysis.

There are Aeromedical Policy Letters, Waivers, Flight Surgeon Guidelines, Air Publications, and Clinical Practice Guidelines, produced by the US Army [132], USN/USAF [133], [134], CAF [135], RAAF, and RAF [136] (used for aircrew in Royal Navy and Army Air Corps), and American Society of Aerospace Medicine Specialists, respectively, which outline how to manage the conditions listed above. Details of these documents are beyond the scope of this report but should be referred to if/when any of the aforementioned conditions are diagnosed.

4.6.4 Aeromedical Disposition as a Spectrum

Aeromedical disposition is a spectrum, anchored on one end by unrestricted flight duties and complete grounding on the other. This spectrum mirrors those of pain, associated signs and symptoms, and the resulting functional capacity. Unfortunately, as symptoms increase and function decreases, in order to prevent further injury and ensure mission safety, MELs must become more restrictive. Acknowledging these requirements, the intent is to preserve and retain trained assets in active flying positions for as long as possible. Further, it should not be assumed that restrictions applied will become permanent. Rather, the intent of all the interventions outlined in this report is to minimise pain/injury and its impact on function with the ultimate goal of returning these people to full function and unrestricted flight duty as soon as possible. As aircrew transition along the spectrum in either direction, the MELs will follow as appropriate.

4.6.5 Nation-Specific Aeromedical Considerations

As with the medical management of aircrew as patients, each nation will have a slightly different approach to the aeromedical considerations surrounding neck pain and determination of the aeromedical disposition for their aircrew. The risk analysis and degree of acceptable risk is an important aspect of determination of aeromedical disposition. Some nations are more accepting of risk while others are more risk averse; this will impact the applied operational definition of neck pain for each nation accordingly. The end result is that most countries manage each aircrew file related to neck pain on a case by case basis.

4.6.6 HFM-252-Recommended Aeromedical Disposition Approach for Aircrew with Neck Pain

This report focuses primarily on the prevention, diagnosis and management of flight-related acquired neck pain. Currently, very few countries have an established protocol for managing this type of neck pain; consequently, the NATO HFM-252 RTG has endeavoured to provide guidance in this area.

All contributors to this report agree that the degree of flight-related neck pain and functional impact of pain and/or disability are the most important factors to consider when determining aeromedical disposition. It is important to recognise that policy regarding aeromedical disposition remains the responsibility of each individual nation and no nation will be held to a 'NATO standard' in terms of aeromedical disposition. Many nations will continue to assess aircrew on a case-by-case basis. However, the following approach to managing aeromedical disposition in aircrew with flight-related neck pain is offered as a 'Best Practice' recommendation.

This approach is intended to address the non-specific severe, persistent, and/or recurrent episodes of flight-related neck pain which are not specifically covered by any other nation-specific protocols for aforementioned diagnoses and/or in the absence of a nation-specific protocol on neck pain in aircrew.

Initial Aircrew Applicants: A history of recurrent or persistent neck pain should be disqualifying for initial aircrew applicants. While aeromedical certification will not normally be considered favourably, it may be reviewed on a case-by-case basis.

Trained Personnel: Aeromedical certification should be favourably considered if the aircrew can safely perform all flight duties and the neck pain:

- Is not associated with a specific condition that adversely affects safety;
- Is not associated with significant loss of neuromuscular function;
- Has been easily and well controlled with occasional use of approved Over-The-Counter (OTC) medications / NSAIDs;
- Does not require the regular use of prescription medications;
- Does not require regular access to medical specialty services;
- Does not impact mission capacity, flight safety, or egress/rescue; and
- Has not resulted in significant/frequent lost duty time.

4.6.6.1 Information Required

Aeromedical Summary (AMS): A summary of the clinical history, physical examination and management plan is required when determining aeromedical disposition. The AMS should include:

- Aircrew current role, flying history, including history of HSM use and other potential contributing factors.

- Detailed clinical history, specifically addressing pain, provocative manoeuvres, radicular symptoms, other associated symptoms, history of trauma/spinal injury/ejection and any treatment modalities used to date (including medication/substance use) and their impact on pain and function.
- Sufficient evidence to exclude prolapsed (herniated) intervertebral discs, structural spinal disease (degenerative disease, spondylolysis or spondylolisthesis), spinal injury (fractures), metabolic bone disease, metastatic lesions, myeloma, ankylosing spondylitis, rheumatoid arthritis, infection, or other structural defects and injury.
- Flight Surgeon or Physiotherapist documentation of physical examination of neck, shoulder, back, and core to address mobility, range of motion, strength, and peripheral neuro-motor-sensory function.
- Laboratory studies only as clinically indicated.
- Imaging studies (X-ray, CT, or MRI) and nerve conduction studies only as clinically indicated.
- Physical Therapy, Orthopaedic Surgery, and/or Rheumatology Consult Report (as appropriate).
- Summary of current level of physical activity, exercise habits/programmes, and any limitations.
- Outcome of most recent mandated physical fitness testing scores.
- Outcome of presumptive evidence of physical fitness (e.g., completed training/courses/deployment with a significant physical component).
- Outcome of cockpit ergonomic/functional assessment as clinically indicated.
- Relevant diagnoses.
- Current management plan, including physical therapy/rehabilitation.
- Additional/outstanding investigations required.
- Follow-up plan, including recommended future treatment.
- Recommended medical employment limitations and aeromedical disposition.

In terms of imaging, although many countries will require X-rays of the cervical spine to rule out any significant pathology (or to start physical therapy), MRI is the preferred imaging modality in most countries. Some countries place high emphasis on imaging results when determining aeromedical disposition. For example:

1) German Air Force:
   a) MRI of the brain and complete spine is done at the time of initial pilot selection; any significant pathology identified is disqualifying for an initial applicant, regardless of symptoms.
   b) MRI of the spine is repeated after every 500 hours of flight time; if a large hernia (or neurological symptoms) is present, the pilot is grounded for 3 months.
   c) After 3 months, the pilot is reassessed; if there are no ongoing symptoms or impact to function, the pilot is returned to active flight status.
2) Italy:
   a) MRI of the brain and complete spine is taken at the time of initial pilot selection; any significant pathology identified is disqualifying for an initial applicant, regardless of symptoms.

3) UK RAF:
   a) Asymptomatic radiologically identified cervical spondylosis is compatible with unrestricted flying. However, limitation of cervical movement may affect lookout and a cockpit check is recommended.
4) USAF:
   a) MRI should be obtained on a 1.5 Tesla, or greater, field strength magnet and include T2 weighted images.
   b) If compression fracture is visible, aircrew are grounded for 3 months minimum.
   c) If other type of fracture is visible, aircrew are grounded for 6 months minimum.
   d) In order to be returned to active flight status, MRI of the cervical spine must demonstrate the following:
      i) Cervical disc herniation does not contact or displace the spinal cord.
      ii) Cervical disc herniation does not produce any signal change in the spinal cord or any deformity.
      iii) Cerebrospinal fluid remains visible anterior and posterior to the spinal cord.
      iv) Flexion/Extension Plain C/Spine X-rays usually done if case warranted an MRI.
5) US Army:
   a) Three-month grounding is required for patients with small anterior chip fracture or less than 25% compression.
   b) At 3 months, a patient that is asymptomatic (pain-free, has full ROM, no instability on lateral views, and has no radicular symptoms) may be returned for trial of duty. By 12 months, if still asymptomatic, waiver may be requested.
   c) On a case-by-case basis, cervical spine fractures with more than 25% compression, evidence of instability on lateral views, or radicular symptoms will rarely be considered for waiver.

4.6.6.2 Medical Employment Limitations

4.6.6.2.1 Restrictions Associated with Treatment

As described in the Treatment section of this chapter, simple conservative measures (e.g., remedial exercises, hot/cold packs, and OTCs or NSAIDS) are usually effective; often these treatment modalities will not require prolonged restriction from flight. Employment of bed rest, spinal corsets, muscle relaxants, narcotic analgesics, hypnotics, oral steroid courses, anti-depressants, back injections, and epidural steroids require temporary grounding, with close flight surgeon follow-up and careful re-evaluation prior to return to flight duties. If the use of chronic medications beyond acetaminophen and anti-inflammatories are required to control neck pain, this is typically disqualifying for return to full flight duties.

Surgical interventions always require a period of grounding – after a prescribed waiting period, the aircrew can be reassessed and possibly returned to active flight duties depending upon the nation's processes. Most nations do not specify required waiting periods following spinal surgery and assess each aircrew on a case-by-case basis. However, the UK recommends a return to unrestricted duties (including flying) three months post-discectomy in asymptomatic individuals. The USAF and USN Waiver Guides recommend the following reassessment timings, following surgical intervention:

1) If fusion performed on a pilot, waiting time is usually 6 months; no fusion 3 months.
2) If single-level synthetic disc is placed, waiting time is 6 months (more than 1 level – not waiverable).

Some therapeutic interventions will unfortunately require permanent grounding. For example, Canada, Germany, UK, and USAF all consider cervical spine fusion of > 1 level to be permanently disqualifying for all types of flight. The USAF will consider a waiver for flying non-ejection seat aircraft in those who have had fusion of > 1 level. The USN will consider a waiver in those who have had fusion at two levels for rotary-wing aircraft only. Generally speaking, spinal surgery is permanently disqualifying for flight in high-performance (ejection seat) aircraft, although some nations will waive certain procedures if there is a good post-op outcome.

4.6.6.2.2 Gradual 'Return to Play' Approach

Generally speaking, a scaled approach is recommended when determining aeromedical disposition and assigning MELs. The Return To Play (RTP) approach used in Sport and Exercise Medicine for athletes who have sustained a concussion can also be applied to aircrew with musculoskeletal pain/injuries, including those involving the cervical spine [137]. When athletes with concussion are ready to begin the RTP process, they are permitted to begin with general, low-intensity activity, progressing to moderate/high intensity and sport-specific activity, then to full practice and eventually unrestricted play. Each stage requires a 24-hour period and reassessment for recurrence of symptoms. If the activity triggers significant symptoms, the athlete returns to the previous stage for a further 24 – 48 hours and is reassessed. The athlete must progress through all stages of the process prior to be returned to full unrestricted (contact) play.

This approach can be applied similarly in aircrew. Begin with a relatively low-intensity and low-duration sorties, minimal +Gz exposure (< 3 +Gz) and daytime flight only, allowing for 48 – 72 hours between flights. If this is well tolerated, progress to increased +Gz exposure (higher +Gz and more frequent exposures during a single flight), longer flight duration and more sorties in a given week. The use of a flight simulator is an excellent way to progress the duration of sortie, the use of various ALSE (including additional HSM) and assess for functional capacity and possible pain recurrence/tolerance, all while in a low-risk environment (and without +Gz or significant vibration exposure). The intent is to progress the aircrew through the stages and monitor function, with the eventual goal of returning them to unrestricted flight status.

4.6.6.2.3 Follow-Up Required

Frequent follow-up and periodic reassessment by a flight surgeon is another way to minimise the risk of remaining on / returning to active flight status. Many countries require a three-month re-assessment period following a significant injury and most countries require an annual periodic health assessment for all aircrew. In Portugal, all pilots meet with a Flight Surgeon every six months and must complete a health questionnaire (which includes specific questions regarding neck and back pain). If a pilot has been grounded for neck pain for five days, he/she must be assessed by a physiatrist to further assess the issue. After a month of grounding, the pilot is sent to the Portugal Air Force Health Board for further review and determination of disposition.

In countries where a 'waiver is granted' (USAF, USN, US Army) for neck pain/injury, the waiver must be 'reviewed' (i.e., resubmitted) by the flight surgeon annually to confirm that there are no new deficits or significant potential for progression. Progression of pain, worsening of symptoms, increased lost duty-time, or emergence of new findings/limitations will mandate complete re-evaluation, advanced imaging and specialty consultation followed by re-submission of the Aeromedical Summary for further review [131]. Conversely, if the condition improves (or resolves) such that the risk to person and mission are less, the 'waiver review' period could be extended to every 2, 3, or 5 years or only as required. The frequency of the reassessment period will be unique to each Force and largely dependent on the risk analysis/tolerance of that nation.

4.6.6.2.4 Suggested Restrictions

Where possible, consider the use of the following restrictions to minimise or eliminate exposures to specific stressors of flight which are potential contributing factors to neck pain. This is particularly important when attempting to return aircrew to flight following an injury. Ideally these restrictions will be temporary and the aircrew will return to full function after a period of rest and treatment. However, if the condition does not improve, these restrictions can also be applied to permanently remove aircrew from high-risk environments:

- Unfit ejection-seat/high-performance aircraft (to minimise +Gz / fast jet environment exposure);
- Unfit rotary-wing aircraft (to minimise vibration / rotary-wing environment exposure);
- May not exceed use of NVG/HSM devices for > 2 hrs consecutively (to minimise HSM exposure); and
- May not fly with or as co-pilot (to minimise the risk associated with sudden incapacitation).

4.7 RECOMMENDATIONS

Chapter 4 (Neck Pain Prevention and Management – Human Factors) reviewed a wide range of factors and strategies potentially affecting the health and performance of aircrew with neck pain and by consensus offer the following recommendations. Included in the discussion are the preventative topics of aircrew exercise training; crew recovery time (e.g., after a minor episode of in-flight neck pain); and G limitations for at-risk aircrew. Neck pain intervention modalities were also reviewed, including a range of treatment strategies for acute, sub-acute, and chronic neck pain. National practices for the aeromedical disposition of aircrew neck pain (i.e., flying status determinations) were also reviewed. Targeted exercise training, in the context of a comprehensive aircrew conditioning programme (e.g., the 'professional athlete model'), is probably effective in reducing the risk and/or consequences of neck pain in aircrew. Although supporting data are not yet available from the aviation community, there is evidence from the sports medicine literature to support a holistic approach to wellness that addresses specific injury patterns. The Task Group has suggested standardized approaches to basic neck pain symptoms in aircrew, but there is no single most effective treatment modality for all aircrew.

Recommendation 4.1 (Sections 4.2.1 and 4.2.2): The overarching recommendation is that aircrew education focuses on a holistic, total lifestyle approach. Aircrew education in combination with all other solutions should lower injury risk.

Recommendation 4.2 (Sections 4.2.3, 4.2.4, and 4.3): A comprehensive multifaceted aircrew conditioning programme that includes enhanced physiotherapy support is recommended to all NATO air forces. Programmes should collect data that can be used later to determine effectiveness and cost/benefit of such conditioning programmes.

Recommendation 4.3 (Section 4.2.3): Several NATO countries are in the process of implementing some or all of the principles behind the Professional Athlete Model. It is recommended that countries pool their experiences and effectiveness data. Non-participating countries may monitor progress and consider implementation, if results from long-term practice are positive.

Recommendation 4.4 (Section 4.4): Extended rest as recommended by research and sports medicine experts may not be operationally feasible. However, when operations allow aircrew, especially those experiencing flight-related neck pain, should be allowed time to rest so that muscles can recover. In particular, work needs to be done to quantify the relationship between time of rest and quality of rest to develop an optimal balance between operational and physiological requirements. For example, while the mandatory 12-hour rest before a mission may be sufficient for cognitive recovery, depending on the non-flying activity performed, this may be insufficient for muscle recovery. Therefore, it is recommended that aircrew take the opportunity to rest their muscles whenever possible.

Recommendation 4.5 (Section 4.5.1): NATO air forces should invest in secondary prevention injury strategies in additional to the common practice of treatment. These include the following:

1) Initial intervention for acute problems should occur on the same calendar day or at the latest on the next calendar day. This requires a 24/7 on-call schedule for a physiotherapist or an alternate staff person, just as the flight surgeons may maintain.
2) Special training in aerospace medicine for staff that see the aircrew.
3) A physiotherapist or a similar occupation should deploy with the unit, just as the flight surgeon does.

Recommendation 4.6 (Section 4.6.6): Aeromedical disposition approaches for aircrew with neck pain should involve initial aircrew applicants, trained personnel, aeromedical summary, restrictions associated with treatment, gradual 'return to play' approach, follow-up, and suggested restrictions.

4.8 REFERENCES

[1] Drew, M.K., Cook, J., and Finch, C.F. (2016). Sports-related workload and injury risk: Simply knowing the risks will not prevent injuries: Narrative review. Br J Sports Med, 50(21), 1306-1308. doi: 10.1136/bjsports-2015-095871.

[2] Jacobsson, J., and Timpka, T. (2015). Classification of prevention in sports medicine and epidemiology. Sports Med, 45(11), 1483-1487. doi: 10.1007/s40279-015-0368-x.

[3] Perry, B., Farrell, P.S.E., and Carnduff, L. (2018). Assessing education and exercise as solutions for aircrew neck-trouble: A literature review: DRDC-RDDC-2018-D016, Defence Research and Development Canada, Toronto, Canada.

[4] Sovelius, R., Oksa, J., Rintala, H., and Siitonen, S. (2008). Neck and back muscle loading in pilots flying high G(z) sorties with and without lumbar support. Aviat Space Environ Med, 79(6), 616-619.

[5] Cote, P., van der Velde, G., Cassidy, J.D., Carroll, L.J., Hogg-Johnson, S., Holm, L.W., et al. (2008). The burden and determinants of neck pain in workers: Results of the Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders. Spine (Philadelphia, PA, 1976), 33(4 Suppl), S60-74. doi: 10.1097/BRS.0b013e3181643ee4.

[6] Kankaanpää, J. (2015). Ilmavoimien ohjaajaopiskelijoiden fyysinen suorituskyky vuosina 2005 – 2014. National Defence University, Helsinki, Finland. Retrieved from http://urn.fi/URN:NBN:fi-fe2015102615060.

[7] Forces, G.A. (2017). C2-800/0-200-3 Bereichsrichtlinie: Fliegerärztlicher Dienst der Bundeswehr, 2017 Jun, 42-6 Kuren zur Erhaltung der Wehrfliegerverwendungsfähigkeit, Germany: German Armed Forces.

[8] Fry, R.W., Morton, A.R., and Keast, D. (1991). Overtraining in athletes. An update. Sports Med, 12(1), 32-65. doi: 10.2165/00007256-199112010-00004.

[9] Schumann, M., Eklund, D., Taipale, R.S., Nyman, K., Kraemer, W.J., Hakkinen, A., ... Hakkinen, K. (2013). Acute neuromuscular and endocrine responses and recovery to single-session combined endurance and strength loadings: "Order effect" in untrained young men. J Strength Cond Res, 27(2), 421-433. doi: 10.1519/JSC.0b013e31827f4a10.

[10] Balldin, U.I., Werchan, P.M., French, J., and Self, B. (2003). Endurance and performance during multiple intense high +Gz exposures with effective anti-G protection. Aviat Space Environ Med, 74(4), 303-308.

[11] Oksa, J., Hamalainen, O., Rissanen, S., Salminen, M., and Kuronen, P. (1999). Muscle fatigue caused by repeated aerial combat maneuvering exercises. Aviat Space Environ Med, 70(6), 556-560.

[12] American Dietetic Association, Dietitians of Canada, American College of Sports Medicine, Rodriguez, N.R., Di Marco, N.M., and Langley, S. (2009). American College of Sports Medicine position stand. Nutrition and athletic performance. Med Sci Sports Exerc, 41(3), 709-731. doi: 10.1249/MSS.0b013e31890eb86.

[13] Billings, C.E. (2004). Epidemiology of injuries and illnesses during the United States Air Force Academy 2002 Basic Cadet Training Program: Documenting the need for prevention. Mil Med, 169(8), 664-670.

[14] Stark, A.H., Weis, N., Chapnik, L., Barenboim, E., and Reifen, R. (2008). Dietary intake of pilots in the Israeli Air Force. Mil Med, 173(8), 780-784.

[15] Reinhart, R. (2007). Basic Flight Physiology (3rd Edition). New York, NY: McGraw-Hill Education.

[16] Roberts, A.C., Butterfield, G.E., Cymerman, A., Reeves, J.T., Wolfel, E.E., and Brooks, G.A. (1996). Acclimatization to 4,300-m altitude decreases reliance on fat as a substrate. J Appl Physiol (1985), 81(4), 1762-1771. doi: 10.1152/jappl.1996.81.4.1762.

[17] Swenson, E.R., Duncan, T.B., Goldberg, S.V., Ramirez, G., Ahmad, S., and Schoene, R.B. (1995). Diuretic effect of acute hypoxia in humans: Relationship to hypoxic ventilatory responsiveness and renal hormones. J Appl Physiol (1985), 78(2), 377-383. doi: 10.1152/jappl.1995.78.2.377.

[18] Lindseth, G., and Lindseth, P.D. (1995). The relationship of diet to airsickness. Aviat Space Environ Med, 66(6), 537-541.

[19] Copp, E.K., and Green, N.R. (1991). Dietary intake and blood lipid profile survey of fighter pilots at Tyndall Air Force Base. Aviat Space Environ Med, 62(9 Pt 1), 837-841.

[20] Hart, S., and Morrison, C. (1992). Effect of age, family status, and physical activity on selected dietary components of TAC pilots. Mil Med, 157(8), 397-401.

[21] Lindseth, P.D., Lindseth, G.N., Petros, T.V., Jensen, W.C., and Caspers, J. (2013). Effects of hydration on cognitive function of pilots. Mil Med, 178(7), 792-798. doi: 10.7205/MILMED-D-13-00013.

[22] Nunneley, S.A., and Stribley, R.F. (1979). Heat and acute dehydration effects on acceleration response in man. J Appl Physiol Respir Environ Exerc Physiol, 47(1), 197-200. doi: 10.1152/jappl.1979.47.1.197.

[23] Sather, T.E., and Woolsey, C.L. (2013). The safety and effectiveness of supplement use in aviation. The Sport Journal, 10.

[24] Shaw, R.V. (2010). Dehydration and the Pilot. Airman Education Programs, Federal Aviation Administration. https://www.faa.gov/pilots/training/airman_education/topics_of_interest/dehydration/.

[25] Schlabach, G. (1994). Carbohydrate strategies for injury prevention. J Athl Train, 29(3), 244-254.

[26] Snyder, A.C. (1998). Overtraining and glycogen depletion hypothesis. Med Sci Sports Exerc, 30(7), 1146-1150.

[27] Lindseth, G.N., Lindseth, P.D., Jensen, W.C., Petros, T.V., Helland, B.D., and Fossum, D.L. (2011). Dietary effects on cognition and pilots' flight performance. Int J Aviat Psychol, 21(3), 269-282. doi: 10.1080/10508414.2011.582454.

[28] Myers, T.W. (2014). Anatomy trains: Myofascial meridians for manual and movement therapists 3rd Ed. London, UK: Churchill Livingstone.

[29] Bordoni, B., and Zanier, E. (2013). Anatomic connections of the diaphragm: Influence of respiration on the body system. J Multidiscip Healthc, 6, 281-291. doi: 10.2147/JMDH.S45443.

[30] Pizzi, C. (1999). Il dolore cervicale e scapolo-omerale nel paziente affetto da broncopneumopatia cronica ostruttiva Il rachide cervicale, aspetti chinesiologici, biomeccanici, neurofisiologici, psicosomatici, posturali, riabilitativi (pp. 531-540). Italy: Marrapese.

[31] Raggi, D. (1999). L'allungamento muscolare globale decompensato in relazione alle patologie osteo-muscolari Il rachide cervicale: Aaspetti chinesiologici, biomeccanici, neurofisiologici, psicosomatici, posturali, riabilitativi (pp. 541-557). Italy: Marrapese.

[32] Thoolen, S.J., and van den Oord, M.H. (2015). Modern air combat developments and their influence on neck and back pain in F-16 pilots. Aerosp Med Hum Perform, 86(11), 936-941. doi: 10.3357/AMHP.4303.2015.

[33] Nüsse, R. (2015). "Pro-vention" – ein Modell zur Gesundheitsfürsorge und psycho-physischen Leistungs-optimierung. Wehrmedizinische Monatsschrift, 59(9-10), 306-311.

[34] Brunetti, G. (2010). Allenare l'atleta. Manuale di metodologia dell'allenamento sportivo. Italy: Edizioni Scuola dello Sport.

[35] Brisswalter, J., Arcelin, R., Audiffren, M., and Delignieres, D. (1997). Influence of physical exercise on simple reaction time: Effect of physical fitness. Percept Mot Skills, 85(3 Pt 1), 1019-1027. doi: 10.2466/pms.1997.85.3.1019.

[36] Colcombe, S., and Kramer, A.F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. Psychol Sci, 14(2), 125-130. doi: 10.1111/1467-9280.t01-1-01430.

[37] Schulz, K.H., Meyer, A., and Langguth, N. (2012). [Exercise and psychological well-being]. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz, 55(1), 55-65. doi: 10.1007/s00103-011-1387-x.

[38] Zhao, E., Tranovich, M.J., DeAngelo, R., Kontos, A.P., and Wright, V.J. (2016). Chronic exercise preserves brain function in masters athletes when compared to sedentary counterparts. Phys Sportsmed, 44(1), 8-13. doi: 10.1080/00913847.2016.1103641.

[39] Quillen, W.S., and Rouillier, L.H. (1982). Initial management of acute ankle sprains with rapid pulsed pneumatic compression and cold. J Orthop Sports Phys Ther, 4(1), 39-43. doi: 10.2519/jospt.1982.4.1.39.

[40] Van Rompay, A., and Duvigneaud, N. (2018). Embedded physiotherapist during Operation Desert Falcon as a result of the survey on neck and back pain in BEL F-16 pilots. Paper presented at the RAMS/USAF and NATO STO Technical Course, Ramstein Air Force Base, Germany.

[41] Wascher, D.C., and Bulthuis, L. (2014). Extremity trauma: Field management of sports injuries. Curr Rev Musculoskelet Med, 7(4), 387-393. doi: 10.1007/s12178-014-9242-y.

[42] Cross, K.M., and Serenelli, C. (2003). Training and equipment to prevent athletic head and neck injuries. Clin Sports Med, 22(3), 639-667.

[43] Marriot, J.A., Reilly, T., and Miles, A. (1993). The effect of physiological stress on cognitive performance in a simulation of soccer. In: T. Reilly, J. Clarys, and A. Stibbe (Eds.), Science and Footfall II (pp. 261-264). London, UK: Taylor and Francis.

[44] McMorris, T., and Graydon, J. (1997). The effect of exercise on cognitive performance in soccer-specific tests. J Sports Sci, 15(5), 459-468. doi: 10.1080/026404197367092.

[45] Fallowfield, J.L., Davey, T., and Greenish, T. (2015). Aircrew nutrition: Guidance for rotary wing and fast jet transits. UK: 2015.003, Institute of Naval Medicine.

[46] Kearns, M.C., Ressler, K.J., Zatzick, D., and Rothbaum, B.O. (2012). Early interventions for PTSD: A review. Depress Anxiety, 29(10), 833-842. doi: 10.1002/da.21997.

[47] Rosenbaum, S., Vancampfort, D., Steel, Z., Newby, J., Ward, P.B., and Stubbs, B. (2015). Physical activity in the treatment of post-traumatic stress disorder: A systematic review and meta-analysis. Psychiatry Res, 230(2), 130-136. doi: 10.1016/j.psychres.2015.10.017.

[48] Sovelius, R., Oksa, J., Rintala, H., Huhtala, H., Ylinen, J., and Siitonen, S. (2006). Trampoline exercise vs. strength training to reduce neck strain in fighter pilots. Aviat Space Environ Med, 77(1), 20-25.

[49] Rintala, H., Hakkinen, A., Siitonen, S., and Kyrolainen, H. (2015). Relationships between physical fitness, demands of flight duty, and musculoskeletal symptoms among military pilots. Mil Med, 180(12), 1233-1238. doi: 10.7205/MILMED-D-14-00467.

[50] Slungaard, E., Green, N.D.C., Newham, D.J., and Harridge, S.D.R. (2018). Content validity of level two of the Royal Air Force Aircrew Conditioning Programme. Aerosp Med Hum Perform, 89(10), 896-904. doi: 10.3357/AMHP.4994.2018.

[51] Äng, B.O., Monnier, A., and Harms-Ringdahl, K. (2009). Neck/shoulder exercise for neck pain in air force helicopter pilots: A randomized controlled trial. Spine, 34(16), E544-E551.

[52] Salmon, D.M., Harrison, M.F., and Neary, J.P. (2011). Neck pain in military helicopter aircrew and the role of exercise therapy. Aviat Space Environ Med, 82(10), 978-987.

[53] Jaeschke, R., Singer, J., and Guyatt, G.H. (1989). Measurement of health status. Ascertaining the minimal clinically important difference. Control Clin Trials, 10(4), 407-415.

[54] Kamper, S.J., Maher, C.G., and Mackay, G. (2009). Global rating of change scales: A review of strengths and weaknesses and considerations for design. J Man Manip Ther, 17(3), 163-170. doi: 10.1179/jmt.2009.17.3.163.

[55] Fusina, G., Karakolis, T., Xiao, A., Farrell, P.S.E., McGuinness, C., and Apostoli, C. (2018). Towards a 'smart-scheduling' mitigating solution for Griffon aircrew neck trouble. DRDC-RDDC-2018-R186, Toronto, Canada: Defence Research and Development Canada.

[56] Tack, D.W., Bray-Miners, J., Nakaza, E.T., Osborne, A., and Mangan, B. (2014). Griffon Helicopter Neck Strain Project. Part 1: Mission function task analysis and physical demands analysis report. Part 2: Physical demands analysis library. (p. 340). Toronto, Canada: Scientific Authority: Philip S.E. Farrell, Ph.D., DRDC-RDDC-2014-C228, Defence Research and Development Canada.

[57] Westerlund, T. (2015). Stress and recovery of players in Kontinental Hockey League. (Bachelor in Sports and Leisure Management), Haaga-Helia University of Applied Sciences, Helsinki, Finland.

[58] Karakolis, T., Farrell, P., and Fusina, G. (2015). Neck overuse injury in CH-146 Griffon helicopter aircrews. Procedia Manufacturing., 3:4205-4212. doi: 10.1016/j.promfg.2015.07.396.

[59] Childress, M.A., and Becker, B.A. (2016). Nonoperative management of cervical radiculopathy. Am Fam Physician, 93(9), 746-754.

[60] Cohen, S.P. (2015). Epidemiology, diagnosis, and treatment of neck pain. Mayo Clin Proc, 90(2), 284-299. doi: 10.1016/j.mayocp.2014.09.008.

[61] Woods, B.I., and Hilibrand, A.S. (2015). Cervical radiculopathy: Epidemiology, etiology, diagnosis, and treatment. J Spinal Disord Tech, 28(5), E251-259. doi: 10.1097/BSD.0000000000000284.

[62] Leichtle, U.G., Wunschel, M., Socci, M., Kurze, C., Niemeyer, T., and Leichtle, C.I. (2015). Spine radiography in the evaluation of back and neck pain in an orthopaedic emergency clinic. J Back Musculoskelet Rehabil, 28(1), 43-48. doi: 10.3233/BMR-140488.

[63] Evans, G. (2014). Identifying and treating the causes of neck pain. Med Clin North Am, 98(3), 645-661. doi: 10.1016/j.mcna.2014.01.015.

[64] Nordin, M., Carragee, E.J., Hogg-Johnson, S., Weiner, S.S., Hurwitz, E.L., Peloso, P.M., et al. (2008). Assessment of neck pain and its associated disorders: Results of the Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders. Spine (Philadelphia, PA, 1976), 33(4 Suppl), S101-122. doi: 10.1097/BRS.0b013e3181644ae8.

[65] Enthoven, W.T., Roelofs, P.D., Deyo, R.A., van Tulder, M.W., and Koes, B.W. (2016). Non-steroidal anti-inflammatory drugs for chronic low back pain. Cochrane Database Syst Rev, 2, CD012087. doi: 10.1002/14651858.CD012087.

[66] van Tulder, M.W., Touray, T., Furlan, A.D., Solway, S., Bouter, L.M., and Cochrane Back Review Group (2003). Muscle relaxants for nonspecific low back pain: A systematic review within the framework of the Cochrane collaboration. Spine (Philadelphia, PA, 1976), 28(17), 1978-1992. doi: 10.1097/01.BRS.0000090503.38830.AD.

[67] Balakrishnamoorthy, R., Horgan, I., Perez, S., Steele, M.C., and Keijzers, G.B. (2015). Does a single dose of intravenous dexamethasone reduce symptoms in emergency department patients with low back pain and radiculopathy (SEBRA)? A double-blind randomised controlled trial. Emerg Med J, 32(7), 525-530. doi: 10.1136/emermed-2013-203490.

[68] Ghasemi, M., Masaeli, A., Rezvani, M., Shaygannejad, V., Golabchi, K., and Norouzi, R. (2013). Oral prednisolone in the treatment of cervical radiculopathy: A randomized placebo-controlled trial. J Res Med Sci, 18(Suppl 1), S43-46.

[69] Gross, A., Langevin, P., Burnie, S.J., Bedard-Brochu, M.S., Empey, B., Dugas, E., ... LeBlanc, F. (2015). Manipulation and mobilisation for neck pain contrasted against an inactive control or another active treatment. Cochrane Database Syst Rev (9), CD004249. doi: 10.1002/14651858.CD004249.pub4.

[70] Patel, K.C., Gross, A., Graham, N., Goldsmith, C.H., Ezzo, J., Morien, A., and Peloso, P.M. (2012). Massage for mechanical neck disorders. Cochrane Database Syst Rev (9), CD004871. doi: 10.1002/14651858.CD004871.pub4.

[71] Trinh, K.V., Graham, N., Gross, A.R., Goldsmith, C.H., Wang, E., Cameron, I.D., ... Cervical Overview Group. (2006). Acupuncture for neck disorders. Cochrane Database Syst Rev (3), CD004870. doi: 10.1002/14651858.CD004870.pub3.

[72] Ernst, E., Lee, M.S., and Choi, T.Y. (2011). Acupuncture: Does it alleviate pain and are there serious risks? A review of reviews. Pain, 152(4), 755-764. doi: 10.1016/j.pain.2010.11.004.

[73] Kroeling, P., Gross, A., Houghton, P.E., and Cervical Overview Group. (2005). Electrotherapy for neck disorders. Cochrane Database Syst Rev (2), CD004251. doi: 10.1002/14651858.CD004251.pub3.

[74] Gross, A., Kay, T.M., Paquin, J.P., Blanchette, S., Lalonde, P., Christie, T., ... Cervical Overview Group. (2015). Exercises for mechanical neck disorders. Cochrane Database Syst Rev, 1, CD004250. doi: 10.1002/14651858.CD004250.pub5

[75] Chumbley, E.M., O'Hair, N., Stolfi, A., Lienesch, C., McEachen, J.C., and Wright, B.A. (2016). Home cervical traction to reduce neck pain in fighter pilots. Aerosp Med Hum Perform, 87(12), 1010-1015. doi: 10.3357/AMHP.4625.2016.

[76] Staal, J.B., de Bie, R., de Vet, H.C., Hildebrandt, J., and Nelemans, P. (2008). Injection therapy for subacute and chronic low-back pain. Cochrane Database Syst Rev (3), CD001824. doi: 10.1002/14651858.CD001824.pub3.

[77] Urquhart, D.M., Hoving, J.L., Assendelft, W.W., Roland, M., and van Tulder, M.W. (2008). Antidepressants for non-specific low back pain. Cochrane Database Syst Rev (1), CD001703. doi: 10.1002/14651858.CD001703.pub3.

[78] Cramer, H., Klose, P., Brinkhaus, B., Michalsen, A., and Dobos, G. (2017). Effects of yoga on chronic neck pain: A systematic review and meta-analysis. Clin Rehabil, 31(11), 1457-1465. doi: 10.1177/0269215517698735.

[79] Kim, S.D. (2016). Effects of yoga on chronic neck pain: A systematic review of randomized controlled trials. J Phys Ther Sci, 28(7), 2171-2174. doi: 10.1589/jpts.28.2171.

[80] Smith, B.H., Elliott, A.M., Chambers, W.A., Smith, W.C., Hannaford, P.C., and Penny, K. (2001). The impact of chronic pain in the community. Family Practice, 18(3), 292-299.

[81] Main, C.J., and Williams, A.C. (2002). Musculoskeletal pain. BMJ, 325(7363), 534-537.

[82] Danneels, L., Beernaert, A., De Corte, K., Descheemaeker, F., Vanthillo, B., Van Tiggelen, D., and Cagnie, B. (2011). A didactical approach for musculoskeletal physiotherapy: The planetary model. Journal of Musculoskeletal Pain, 19(4), 218-224.

[83] Misailidou, V., Malliou, P., Beneka, A., Karagiannidis, A., and Godolias, G. (2010). Assessment of patients with neck pain: A review of definitions, selection criteria, and measurement tools. J Chiropr Med, 9(2), 49-59. doi: 10.1016/j.jcm.2010.03.002.

[84] Kendall, N.A.S., Linton, S.J., and Main, C.J. (1997). Guide to assessing psychosocial yellow flags in acute low back pain: Risk factors for long term disability and work loss. New Zealand: Accident and Compensation Commission of New Zealand and the National Health Committee.

[85] Bertozzi, L., Gardenghi, I., Turoni, F., Villafane, J.H., Capra, F., Guccione, A.A., and Pillastrini, P. (2013). Effect of therapeutic exercise on pain and disability in the management of chronic nonspecific neck pain: Systematic review and meta-analysis of randomized trials. Phys Ther, 93(8), 1026-1036. doi: 10.2522/ptj.20120412.

[86] Childs, J.D., Cleland, J.A., Elliott, J.M., Teyhen, D.S., Wainner, R.S., Whitman, J.M., ... American Physical Therapy Association. (2008). Neck pain: Clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopedic Section of the American Physical Therapy Association. J Orthop Sports Phys Ther, 38(9), A1-A34. doi: 10.2519/jospt.2008.0303.

[87] Kay, T.M., Gross, A., Goldsmith, C.H., Rutherford, S., Voth, S., Hoving, J.L., ... Santaguida, P.L. (2012). Exercises for mechanical neck disorders. Cochrane Database Syst Rev (8), CD004250. doi: 10.1002/14651858.CD004250.pub4.

[88] O'Riordan, C., Clifford, A., Van De Ven, P., and Nelson, J. (2014). Chronic neck pain and exercise interventions: Frequency, intensity, time, and type principle. Arch Phys Med Rehabil, 95(4), 770-783. doi: 10.1016/j.apmr.2013.11.015.

[89] Falla, D. (2004). Unravelling the complexity of muscle impairment in chronic neck pain. Man Ther, 9(3), 125-133. doi: 10.1016/j.math.2004.05.003.

[90] Gross, A., Miller, J., D'Sylva, J., Burnie, S.J., Goldsmith, C.H., Graham, N., ... COG. (2010). Manipulation or mobilisation for neck pain: A Cochrane review. Man Ther, 15(4), 315-333. doi: 10.1016/j.math.2010.04.002.

[91] Hurwitz, E.L., Carragee, E.J., van der Velde, G., Carroll, L.J., Nordin, M., Guzman, J., ... Haldeman, S. (2009). Treatment of neck pain: Non-invasive interventions: Results of the Bone and Joint Decade 2000 – 2010 Task Force on Neck Pain and Its Associated Disorders. J Manipulative Physiol Ther, 32(2 Suppl), S141-175. doi: 10.1016/j.jmpt.2008.11.017.

[92] Gross, A.R., Goldsmith, C., Hoving, J.L., Haines, T., Peloso, P., Aker, P., ... Cervical Overview Group. (2007). Conservative management of mechanical neck disorders: A systematic review. J Rheumatol, 34(5), 1083-1102.

[93] Gross, A.R., Hoving, J.L., Haines, T.A., Goldsmith, C.H., Kay, T., Aker, P., ... Cervical Overview Group. (2004). A Cochrane review of manipulation and mobilization for mechanical neck disorders. Spine (Philadelphia, PA, 1976), 29(14), 1541-1548.

[94] Miller, J., Gross, A., D'Sylva, J., Burnie, S.J., Goldsmith, C.H., Graham, N., ... Hoving, J.L. (2010). Manual therapy and exercise for neck pain: A systematic review. Man Ther, 15(4), 334-354.

[95] McCaskey, M.A., Schuster-Amft, C., Wirth, B., Suica, Z., and de Bruin, E.D. (2014). Effects of proprioceptive exercises on pain and function in chronic neck and low back pain rehabilitation: A systematic literature review. BMC Musculoskelet Disord, 15, 382. doi: 10.1186/1471-2474-15-382.

[96] Iqbal, Z.A., Rajan, R., Khan, S.A., and Alghadir, A.H. (2013). Effect of deep cervical flexor muscles training using pressure biofeedback on pain and disability of school teachers with neck pain. J Phys Ther Sci, 25(6), 657-661. doi: 10.1589/jpts.25.657.

[97] Voerman, G.E., Sandsjo, L., Vollenbroek-Hutten, M.M., Larsman, P., Kadefors, R., and Hermens, H.J. (2007). Effects of ambulant myofeedback training and ergonomic counselling in female computer workers with work-related neck-shoulder complaints: A randomized controlled trial. J Occup Rehabil, 17(1), 137-152. doi: 10.1007/s10926-007-9066-3.

[98] Naugle, K.M., Fillingim, R.B., and Riley, J.L., 3rd. (2012). A meta-analytic review of the hypoalgesic effects of exercise. J Pain, 13(12), 1139-1150. doi: 10.1016/j.jpain.2012.09.006.

[99] Radhakrishnan, K., Litchy, W.J., O'Fallon, W.M., and Kurland, L.T. (1990). Epidemiology of cervical radiculopathy: A population-based study from Rochester, Minnesota, 1976 through 1990. Brain, 117, 325-333.

[100] Andersen, K., Baardsen, R., Dalen, I., and Larsen, J.P. (2015). Recurrent and transient spinal pain among commercial helicopter pilots. Aerosp Med Hum Perform, 86(11), 962-969. doi: 10.3357/AMHP.4237.2015.

[101] Kuijper, B., Tans, J.T., Schimsheimer, R.J., van der Kallen, B.F., Beelen, A., Nollet, F., and de Visser, M. (2009). Degenerative cervical radiculopathy: Diagnosis and conservative treatment. A review. Eur J Neurol, 16(1), 15-20. doi: 10.1111/j.1468-1331.2008.02365.x.

[102] Abd-Alrahman, N., Dokmak, A.S., and Abou-Madawi, A. (1999). Anterior cervical discectomy (ACD) versus anterior cervical fusion (ACF): Clinical and radiological outcome study. Acta Neurochir (Wien), 141(10), 1089-1092.

[103] Hacker, R.J., Cauthen, J.C., Gilbert, T.J., and Griffith, S.L. (2000). A prospective randomized multicenter clinical evaluation of an anterior cervical fusion cage. Spine (Philadelphia, PA, 1976), 25(20), 2646-2654; discussion 2655.

[104] Moreland, D.B., Asch, H.L., Clabeaux, D.E., Castiglia, G.J., Czajka, G.A., Lewis, P.J., ... Huynh, L. (2004). Anterior cervical discectomy and fusion with implantable titanium cage: Initial impressions, patient outcomes and comparison to fusion with allograft. Spine J, 4(2), 184-191; discussion 191. doi: 10.1016/j.spinee.2003.05.001.

[105] Nandoe Tewarie, R.D., Bartels, R.H., and Peul, W.C. (2007). Long-term outcome after anterior cervical discectomy without fusion. Eur Spine J, 16(9), 1411-1416. doi: 10.1007/s00586-007-0309-y.

[106] Ramadan, A.S., Mitulescu, A., and Schmitt, P. (2007). Total cervical disc replacement with the discocerv (cervidisc evolution) cervical proethesis: Early results of a second generation. European Journal of Orthopaedic Surgery and Traumatology, 17(6), 513-520.

[107] Fay, L.Y., Huang, W.C., Tsai, T.Y., Wu, J.C., Ko, C.C., Tu, T.H., ... Cheng, H. (2014). Differences between arthroplasty and anterior cervical fusion in two-level cervical degenerative disc disease. European Spine Journal, 23(3), 627-634.

[108] Wu, J.C., Huang, W.C., Tsai, H.W., Ko, C.C., Fay, L.Y., Tu, T.H., ... Cheng, H. (2012). Differences between 1- and 2-level cervical arthroplasty: More heterotopic ossification in 2-level disc replacement: Clinical article. J Neurosurg Spine, 16(6), 594-600. doi: 10.3171/2012.2.SPINE111066.

[109] Chang, H.K., Huang, W.C., Wu, J.C., Tu, T.H., Fay, L.Y., Chang, P.Y., ... Cheng, H. (2015). Cervical arthroplasty for traumatic disc herniation: An age- and sex-matched comparison with anterior cervical discectomy and fusion. BMC Musculoskelet Disord, 16, 228. doi: 10.1186/s12891-015-0692-1.

[110] Chiu, J.C. (2008). Endoscopic assisted microdecompression of cervical disc and foramen. Surg Technol Int, 17, 269-279.

[111] Schebesch, K.M., Albert, R., Schodel, P., Proescholdt, M., Lange, M., and Brawanski, A. (2011). A single neurosurgical center's experience of the resolution of cervical radiculopathy after dorsal foraminotomy and ventral discectomy. J Clin Neurosci, 18(8), 1090-1092. doi: 10.1016/j.jocn.2010.12.048.

[112] Ries, L.G., and Berzin, F. (2008). Analysis of the postural stability in individuals with or without signs and symptoms of temporomandibular disorder. Braz Oral Res, 22(4), 378-383.

[113] Okeson, J.P. (1996). Orofacial pain: Guidelines for assessment, classification, and management. Oceanville, NJ: The American Academy of Orofacial Pain.

[114] Clark, G.T., Green, E.M., Dornan, M.R., and Flack, V.F. (1987). Craniocervical dysfunction levels in a patient sample from a temporomandibular joint clinic. J Am Dent Assoc, 115(2), 251-256.

[115] Walczynska-Dragon, K., and Baron, S. (2011). The biomechanical and functional relationship between temporomandibular dysfunction and cervical spine pain. Acta Bioeng Biomech, 13(4), 93-98.

[116] Zakrzewska, J.M. (2013). Multi-dimensionality of chronic pain of the oral cavity and face. J Headache Pain, 14, 37. doi: 10.1186/1129-2377-14-37.

[117] Kibana, Y., Ishijima, T., and Hirai, T. (2002). Occlusal support and head posture. J Oral Rehabil, 29(1), 58-63.

[118] Padamsee, M., Mehta, N., Forgione, A., and Bansal, S. (1994). Incidence of cervical disorders in a TMD population. Journal of Dental Research, 73, 186.

[119] De Laat, A., Meuleman, H., Stevens, A., and Verbeke, G. (1998). Correlation between cervical spine and temporomandibular disorders. Clin Oral Investig, 2(2), 54-57.

[120] Inoue, E., Maekawa, K., Minakuchi, H., Nagamatsu-Sakaguchi, C., Ono, T., Matsuka, Y., ... Kuboki, T. (2010). The relationship between temporomandibular joint pathosis and muscle tenderness in the orofacial and neck/shoulder region. Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 109(1), 86-90. doi: 10.1016/j.tripleo.2009.07.050.

[121] Silveira, A., Gadotti, I.C., Armijo-Olivo, S., Biasotto-Gonzalez, D.A., and Magee, D. (2015). Jaw dysfunction is associated with neck disability and muscle tenderness in subjects with and without chronic temporomandibular disorders. Biomed Res Int, 2015, 512792. doi: 10.1155/2015/512792.

[122] Amantéa, D.V., Novaes, A.P., Campolongo, G.D., and de Barros, T.P. (2004). The importance of the postural evaluation in patients with temporomandibular joint dysfunction. Acta Ortopédica Brasileira, 12(3).

[123] Nicolakis, P., Nicolakis, M., Piehslinger, E., Ebenbichler, G., Vachuda, M., Kirtley, C., and Fialka-Moser, V. (2000). Relationship between craniomandibular disorders and poor posture. Cranio, 18(2), 106-112.

[124] Gonzalez, H.E., and Manns, A. (1996). Forward head posture: Its structural and functional influence on the stomatognathic system, a conceptual study. Cranio, 14(1), 71-80.

[125] Bhat, S. (2010). Etiology of temporomandibular disorders: The journey so far. International Dentistry SA, 12(4), 88-92.

[126] Loster, J.E., and Wieczorek, A. (2014). An assessment of the effectiveness of treatment for temporomandibular joint dysfunctions. Dental and Medical Problems, 51(1), 72-78.

[127] Lee, Y.J., Lee, J.K., Jung, S.C., Lee, H.W., Yin, C.S., and Lee, Y.J. (2013). Case series of an intraoral balancing appliance therapy on subjective symptom severity and cervical spine alignment. Evid Based Complement Alternat Med, 2013, 181769. doi: 10.1155/2013/181769.

[128] Walczynska-Dragon, K., Baron, S., Nitecka-Buchta, A., and Tkacz, E. (2014). Correlation between TMD and cervical spine pain and mobility: Is the whole-body balance TMJ related? Biomed Res Int, 2014, 582414. doi: 10.1155/2014/582414.

[129] Lurie, O., Zadik, Y., Einy, S., Tarrasch, R., Raviv, G., and Goldstein, L. (2007). Bruxism in military pilots and non-pilots: Tooth wear and psychological stress. Aviat Space Environ Med, 78(2), 137-139.

[130] Baldini, A., Tecco, S., Cioffi, D., Rinaldi, A., and Longoni, S. (2012). Gnatho-postural treatment in an air force pilot. Aviat Space Environ Med, 83(5), 522-526.

[131] ASAMS. (2008). American Society of Aerospace Medicine Specialists (ASAMS): Clinical Practice Guideline for Chronic Low Back Pain. from http://www.asams.org/guidelines/Completed/NEW%20Back%20Pain_update.htm.

[132] USASAM. (2015). United States Army School of Aviation Medicine (USASAM): Aeromedical Policy Letters and Aeromedical Technical Bulletins. Fort Rucker, AL.

[133] USAFSAM. (2016). United States Air Force School of Aerospace Medicine (USAFSAM): Aircrew Waiver Guide. Dayton, OH: Wright-Patterson Air Force Base.

[134] USNNAMI. (2016). United States Navy Naval Aerospace Medical Institute (USNNAMI): Aeromedical Reference and Waiver Guide. Pensacola, FL: United States Navy Naval Aerospace Medical Institute.

[135] CAF. (2012). Canadian Air Force (CAF): Spinal pain in aircrew. Canada: FSG 1100-01, Department of National Defence.

[136] Royal Air Force Aeromedical Standards, Air Publication AP1269A C.F.R. (2017). United Kingdom.

[137] McCrory, P., Meeuwisse, W., Dvorak, J., Aubry, M., Bailes, J., Broglio, S., ... Vosp, P.E. (2016). Consensus statement on concussion in sport. 5th International Conference on Concussion in Sport held in Berlin, October 2016, British Journal of Sports Medicine, 51(11).

Chapter 5 – NECK PAIN PREVENTION AND MANAGEMENT – BODY-BORNE EQUIPMENT

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5.1 BACKGROUND

A helmet's primary role is to provide protection to prevent injury to the head and face during normal and emergency operations. In addition to providing this protection the helmet system must be capable of balancing requirements associated with physical protection, environmental protection and user acceptability, to maximise aircrew capability (Figure 5-1). To ensure it is fit for service the system must be robust, durable, and comfortable for the wearer.

When helmet systems are specified, there are over two hundred system requirements to ensure all aspects of the helmet are accounted for, and it is often the case that requirements need to be balanced in order to ensure overall capability is met. Understanding this balance is important when considering helmet mass, Centre of Mass (CoM) and Moment of Inertia (MoI), and how the risk of neck pain can be addressed. With additional mass or increased moment, higher muscle force is required to maintain posture and to accelerate and decelerate the head during movements.

In addition to head-supported mass, integration of helmet systems with below-neck equipment can affect posture and movement. All of these factors alter the way the human would normally undertake tasks and thus influence the risk of neck pain.

Helmet systems have evolved since their introduction to serve as a mounting platform for critical life support and operational enhancement technologies, such as communication systems, oxygen/gas masks, Night Vision Goggles (NVGs), and Helmet-Mounted Displays (HMDs). With these new technologies, the mass of the system has increased and the resulting centre of mass is often compromised, made worse by the fact that manufacturers of helmets are often not the suppliers of these other ancillary items, so optimising the design is left up to the client for both the helmet and its ancillary items.

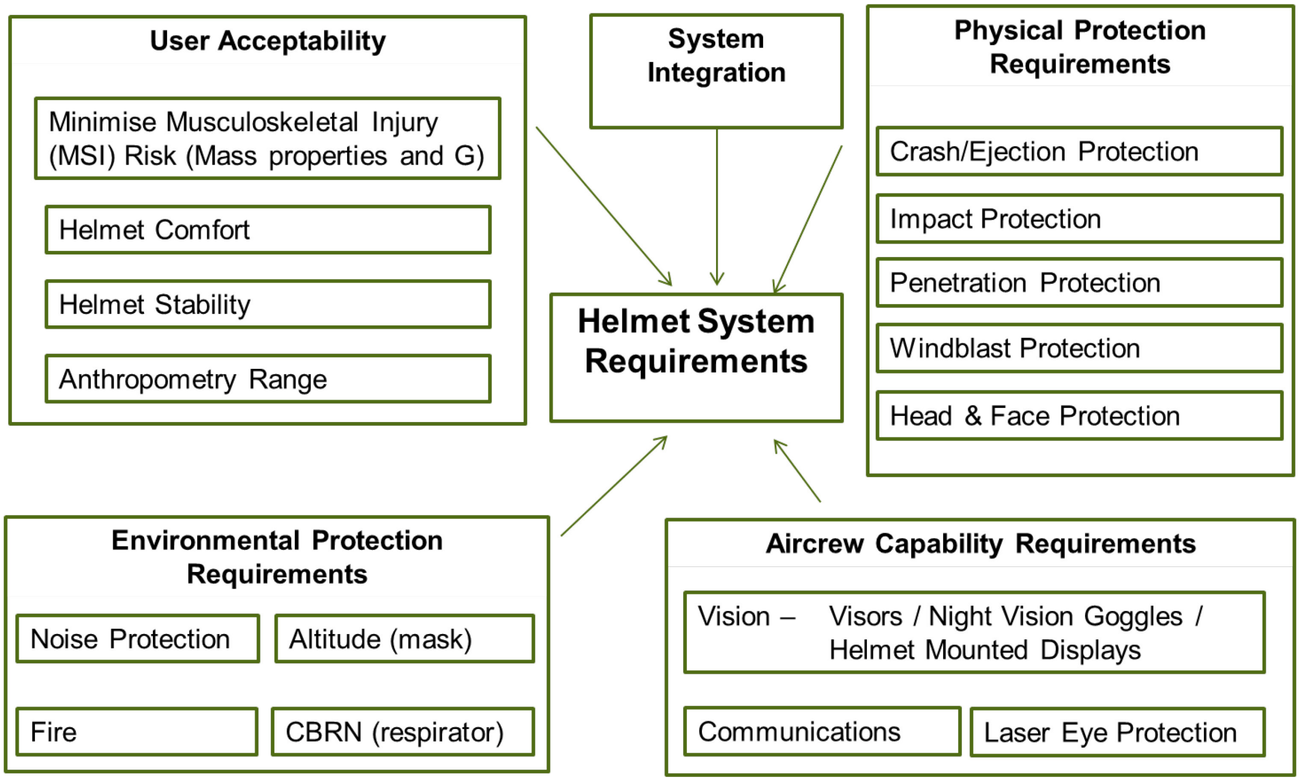

Figure 5-1: Balancing Helmet System Requirements.

In the late 1980s, the US Army began experimenting with NVGs that were designed for ground Soldier use, as an aid to night time helicopter flying [1], [2]. Attaching these goggles to the flight helmet with Velcro straps and rubber tubing, Army aviators learned to fly at night with the myriad of sensory challenges posed by these image intensification systems. The considerable forward shift in head/helmet CoM by attaching the NVGs was accepted by adding the field expedient solution of a simple Counterweight (CW) to the rear of the helmet. Over the years, NVG performance has improved and prevalence increased, while other technologies have been added to the helmet to further increase capability (e.g., NVG HUD or Display NVG). In some aircraft, such as the AH-64 Apache, a monocular display apparatus is attached to the helmet, or in the case of the Eurocopter Tiger, a binocular helmet-mounted display is standard equipment. Similarly, both the Typhoon and F35 aircraft are equipped with integrated display systems that are part of a platform's weapon system and overall platform capability; in these helmets the display and night capability is integrated into the helmet at all times. These improved capabilities come with additional equipment, which means increases in total mass and MoI, and a helmet system imbalance due to a shift in CoM.

Neck pain in aircrew is an ongoing issue and the link between helmet system mass properties and neck pain has been identified in various surveys that have quantified neck pain prevalence amongst aircrew. These surveys have concluded that chronic pain for rotary-wing aircrew may occur after 150 to 200 hours of night flying that involves helmet with NVG, CW, batteries, etc. [3], [4], [5]. This implies two causes of neck pain working in tandem: 1) number of flight hours; and 2) changes in helmet system mass properties. With respect to flight hours, it has been postulated that chronic pain is a neck overuse injury caused by repetitive and high neck loads due to higher-than-normal helmet system mass properties [6]. Neck models show that neck loads are directly related to helmet system mass, centre of mass, and moment of inertia as well as helmet fit [7]. To date, no clinical study has been identified that links aircrew chronic neck pain to number of night flying hours; however, there is enough corroborating evidence from the surveys and the biomechanics of the problem to make the following assumption: **the risk of developing or aggravating aircrew neck pain is reduced by minimising neck load exposure**. Neck load exposure has two components, namely load and exposure time. Number of flying hours is dependent on operational requirements and therefore a key focus should be on optimising the mass properties and fit of the helmet system: specifically making the helmet system lighter, balanced, reducing the moment of inertia, and improving helmet fit.

Spine-associated symptomology and pathology has been a well-recognised health concern for military aviators and aircrew for over 50 years [8], [9], [10], [11], [12], [13], [14]. Spine-associated symptomology and pathology have been and continue to be associated with both fixed and rotary-wing platforms. From 2004 – 2013, intervertebral disc disease was the top primary hospitalization diagnosis for all military aviators and aircrew according to the DMED. Additionally, during the same period, unspecified back disorders, intervertebral disc disorder, and cervical disorders were all within the top ten leading primary ambulatory diagnoses for the same population, with cervical disorder ambulatory visits ranked #10 for fixed wing for all branches of service, #10 for aviator and aircrew military occupations, # 8 for both Navy and Air Force fixed wing, and #10 for Army rotary wing.

A number of observational studies have cited the contribution of NVGs or other HMDs to neck pain. Äng and Harms-Ringdahl (2006) [15] found that a history of NVG use was associated with neck pain, but not significantly so. Greeves and Wickes [16] reported that UK helicopter crews with neck pain had flown significantly more hours than helicopter crews without pain, especially with increased NVG flying hours. Additionally, helicopter front seat aircrew that had flown over 700 hours with NVGs had more than an 80% likelihood of developing flight-related neck pain. Approximately 50% of surveyed U.S. Army helicopter pilots with neck pain attributed their symptoms to the heavy use of NVGs in the deployed setting [17].

Recent aircrew surveys continue to point toward NVG exposure as a primary source of neck pain risk [3]. The 2015 analysis of recent international survey data found that 45% of aircrew report neck pain during flight, which was significantly correlated with the total number of NVG flight hours and the average number of NVG hours per mission, which also predicts pain persisting after the flight [4]. This survey data also suggested that neck pain tended to appear after two hours of NVG flight, contributing to the risk of long NVG missions. RAAF fast jet aircrew strongly linked head-supported mass to flying-related neck pain, for NVGs (6.2 points on a 10-point scale; JHMCS 7.3 points on a 10-point scale). In contrast, high-G flying with a helmet alone was not linked strongly to neck pain (3.2 points on a 10-point scale) [18].

For fast jet aircrew, neck pain prevalence has been related to the G environment, with over 80% of FJ aircrew associated flight-related neck pain with high G [19]. Modern fighter pilots are provided helmet-mounted displays and sighting systems as part of the latest generation of high-performance aircraft. These have predictably resulted in complaints of neck pain and injury [20], [21]. Recently, operational requirements have driven up the duration of sorties and aircrew are citing length of sortie duration and head-mounted equipment as a cause of increased incidence of neck pain in UK Tornado and Typhoon aircrew.

Numerous experiments have been conducted in an effort to quantify the effect of additional Head-Supported Mass (HSM) on neck pain and performance. While the setting of HSM design criteria or exposure limits is a very complex problem, these studies provide insight into the stresses and potential performance effects.

Gallagher, Caldwell, and Albery [22] studied subjects wearing flight helmets with various CoM shifts over an 8-hour period at 1 G, and found significant discomfort after two hours of wear. In this study, a 4.5 lb helmet with a forward CoM shift was less comfortable than a 6 lb helmet with a neutral CoM. Barker and Albery [23] studied 17 volunteers wearing helmet-supported weights ranging from 2.25 to 6.05 lbs for four hours at 1 G. Neck fatigue and discomfort were greater in all the helmet wear configurations; wear time was correlated with neck-related symptoms.

Studies combining HSM with increased +Gz have confirmed the increased muscular load, and that a heavier helmet generates more muscular stress than a lighter helmet under increased +Gz [24]. Other studies have linked increased head-supported mass to subjective fatigue, as well as objective evidence of muscular fatigue [25]. In a recent centrifuge study of four Swedish Air Force pilots, Pousette, Lo Martire, Linder, Kristoffersson, and Ang [26] showed that repeated exposure over 1.5 hrs from +3 to +7 Gz, while wearing NVG, increased EMG muscle activity in the anterior stabilising muscles, which was thought to reflect an elevated risk of flight-related neck pain.

Computer modelling of the high +Gz range, with HSM, confirms that the increased weight and forward CoM shift leads to higher muscle activation and joint reaction loads. These are thought to reflect increased risk of injury [27].

Although counterweights are commonly used with NVGs [17], laboratory evidence has not always shown a benefit. Harrison, Forde, Albert, Croll, and Neary [28] found increased EMG activity, indicating increased muscular workload, with HMDs; the increased activity was not reduced by the use of a counterweight. This result differed from a previous study of operational pilots flying in a flight simulator [29]. The benefit of a counterweight is, no doubt, task- and posture-specific.

Many aspects of HSM performance and physiological effects have not been researched conclusively, including the effects of safe exposure duration and the link between EMG activation and injury prediction [25].

5.2 HEAD-SUPPORTED MASS – PRINCIPLES

Humans can move their unburdened heads in a full range of positions and speeds without any ill effects. Once head-borne systems are added to the head, however, aircrew must adapt their positions and movements to avoid over torqueing or injuring neck structures. Ideally, any head-supported mass would have its CoM as close to the head CoM as possible in order to avoid any additional torque on neck joints. However, the additional mass would contribute to higher compression and shear forces on neck joints, and the additional MoI would require lower acceleration and deceleration of neck movements, again to minimise neck torques.

Thus, three helmet system design principles would be to:

1) Minimise mass;
2) Minimise inertia (i.e., minimise volume); and
3) Ensure that CoM is as close to the head's CoM as possible.

With these design principles, aircrew would have more freedom of posture and movement and a reduced risk of injury.

The importance of appropriate mass properties specifications for achieving a stable and comfortable helmet that minimises injury has been known for quite some time. Many helmet-specification documents have included mass, CoM and MoI or combinations of these properties. The current standards for HSM requirements in HSM design and development are based on risk assessment curves commonly known as the "USAARL Curves" for rotary-wing platforms [30]. These curves were developed in the mid- to late 90s based on research conducted starting in the late 80s, using helmet mass and centre of mass offsets common to helmets fielded at the time. The curves were developed to assess injury and performance decrement risk relative to mass as well as vertical and longitudinal CoM requirements (see Figure 5-2 and Figure 5-3). Vertical CoM variation is thought to be most critical when considering crash-induced severe neck injury risk; whereas, longitudinal CoM variation is important when considering wearer fatigue, performance, and chronic musculoskeletal injury. The USAARL curves attempt to define a moment-loading limit which would account for the combined effect of mass and CoM position in a helmet specification, where the curved portion of the limit lines are based on a constant moment limit i.e., a helmet with higher mass and less offset CoM is equivalent to a lower mass helmet with more offset CoM; however, the curves also have a fixed maximum mass limit of 2.5 kg, which is contrary to this constant moment concept.

Since the development of the USAARL curves, new helmet systems have been fielded and helmet-mounted technologies are continuously being developed for use in aviation. Currently fielded HSM configurations exceed the "worst case" configuration used to develop the mass and longitudinal CoM requirements risk curve. Further research is needed to expand the curves to accommodate and assess currently and future fielded HSM configurations for low-load/long exposures as well as high-load/short exposures. Additionally, sex differences need to be further investigated for exposure duration risk, particularly as performance and user acceptance are affected.

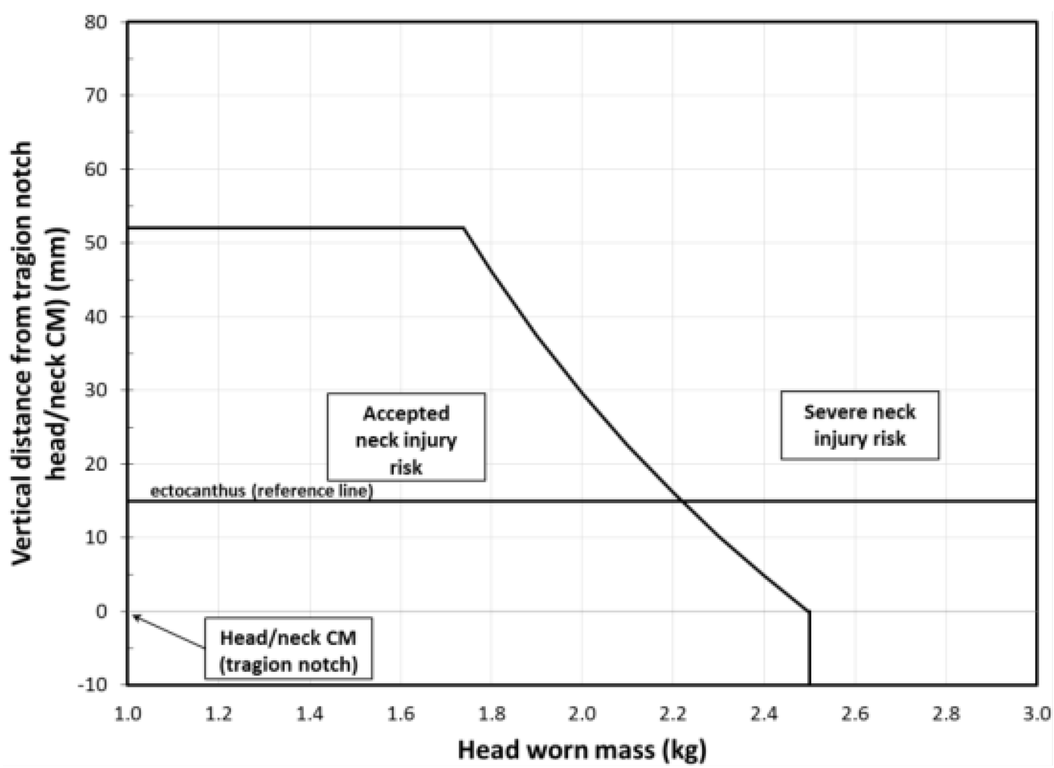

Figure 5-2: Vertical Centre of Mass Placement as a Function of Head-Worn Mass [30].

HSM selection processes and prioritisation of criteria vary greatly between nations. HFM-252 conducted a poll to identify how each nation determined HSM selection criteria. HSM selection criteria were defined in multiple ways: internally developed within a branch of service (U.S. Army (USA), U.S. Air Force (USAF), and UK MOD); adopted from a sister service (U.S. Navy); adopted from a partner nation (France and Australia); specific to a mission or time of day (UK MOD); flight test and user acceptance (the Netherlands and France); or aircraft dependent (F35 jet; newly fielded in most NATO nations). HSM immediate mass and mass positioning have been identified as key considerations in selection criteria. There are multiple U.S., UK, and Canadian efforts, combining volunteer research and modelling, aimed to update or redefine HSM guidelines with particular focus on the role of mass and mass position, including current and emerging HSM configurations used across NATO nations; investigation of the impact of head mass, inertia, movement, and environmental Gz on aircrew neck muscles; derivation of empirical relationships between mass properties, and neck loading and muscle activation; and comparison of operational helmet systems and their likelihood to mitigate chronic neck pain.

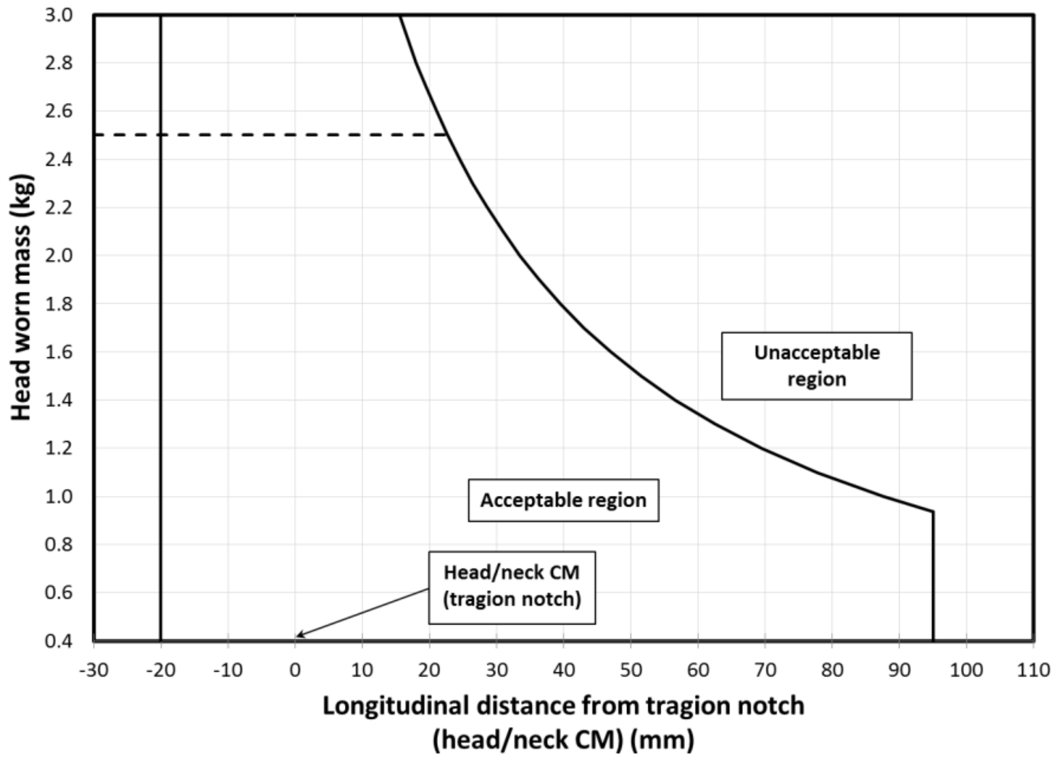

Figure 5-3: Allowable Head-Worn Mass as a Function of Longitudinal Centre of Mass Placement [30].

5.3 HELMET FIT AND STABILITY

Fit of a helmet influences helmet mass properties, with an unstable or poorly fitting helmet resulting in the neck needing to work harder to maintain the same position. The fit of the flight helmet has been identified as a factor contributing to the experienced neck load during flight [31]. With an optimised helmet fit, helicopter aircrew experience less neck load, greater helmet stability, fewer hot spots, and more comfort. Furthermore, helmet stability is negatively associated with the experienced neck load during flight and the experienced neck load is positively associated with experienced neck pain [32]. Although no biomechanical measurements were performed when the effects of an optimised helmet fit were studied, there are some plausible ideas of mechanism to explain the effect of an optimised helmet fit on neck load and pain. First, the stability of the helmet influences the weight distribution of the head-worn mass. An optimised helmet fit contributes to a stable helmet. A stable helmet implies that the CoM of the total head mass is not moving, and therefore not causing continuous alterations in the load moments that impact the cervical spine due to CoM movement. Secondly, when a helmet is unstable, aircrew need to change their head positions continuously to correct for the helmet movements and to keep the NVG aligned with their eyes. This leads to unfavourable postures and increasing neck loads [33], [31]. The increased load caused by different postures seems to have a greater influence on muscle activity than the increased load of the head-worn equipment [34]. And thirdly, an optimised helmet fit prevents aircrew from using too heavy counterweights, increasing the total head-worn mass for the wrong reasons, namely to keep the helmet in place. Aircrew mentioned using counterweights to prevent the helmet from moving during flight [31]:

> *I started with a helmet one size larger and after 1.5 years, I got one size smaller. When I was flying with the larger helmet, I needed much more counterweights just to keep the helmet in place, now I could do without a CW (...) although it is still more comfortable to use a CW because of the better weight distribution, but I do not need it anymore to keep my helmet in place.*

5.3.1 Achieving an Optimised Helmet Fit

While the importance of an optimised fit might be obvious, practice, however, teaches us that this is not easily achieved. The first reason is that discomfort issues play an important role in helmet fit. It is a great challenge to improve the stability of the helmet without causing more discomfort, such as hot spots. This is not desirable because of safety concerns. Strong associations between perceived hot spots and lower ratings of comfort and higher ratings of irritation/distraction during flight have been shown [32]. A second reason is that although a helmet often comes with a manual concerning the fitting process by the helmet provider, a protocol should be evaluated and lessons learned from practice and experience should be incorporated. Furthermore, the separate components of the head-worn mass such as NVGs and HMDs often come from different providers and have their impact on helmet stability and fit. In addition, different inner liners from different providers can be used (provided that this does not affect the impact protection of the helmet), yet will influence helmet stability and fit [32].

Based on the experience within the Royal Netherlands Air Force (RNLAF), three measures are suggested to accomplish an optimised helmet fit. It should be mentioned that this experience is based on optimising the fitting of the HGU-56/P and HGU-55/P helmet [35]. In the RNLAF, specially trained flight equipment technicians perform the helmet fitting with the aircrew.

1) **Improving the helmet fit protocol:** A flight helmet comes with operating instructions including fitting procedures by the provider. Fitting protocols can be improved by critically reviewing the provided protocol, using the experience of aircrew flying with the helmet, the knowledge and experience from the flight equipment technicians, and feedback from and to the helmet provider. The result should be a fitting protocol agreed on / approved by the flight equipment technicians and the provider. Teaching about the fitting procedures to the flight equipment technicians and hands on practice is very important, since optimising an aircrew member's helmet fit does not merely involve following the fitting protocol, but requires professional skills and dedication. Changes in the protocol could involve re-organizing and ordering all steps necessary to fit a helmet; adding fitting checks with the different mounted equipment; insertion of additional warnings at crucial steps within the protocol where mistakes could easily and unnoticeable be made; and providing skilful tricks and tools to aid the technicians during certain steps. Furthermore, a familiarization period (approximately 10 flight hours) should be included in the protocol. Aircrew need to get used to their helmet fit, should evaluate their helmet fit during flight and return to the flight equipment technician after the familiarization period, who should check the helmet fit and adapt if necessary.

2) **Evaluating and renewing with the flight equipment technicians:** The fitting protocol agreed on should be evaluated on a regular basis. Experience could lead to new insights and the knowledge and

experience obtained when fitting the most difficult fitting cases should be shared. Any necessary changes to the fitting protocol should be made accordingly.

3) **Make the aircrew aware of the importance of helmet fit:** Especially when a helmet is first fitted, aircrew have no experience and do not know how a helmet is supposed to fit. Teaching the student pilots about helmet fit and the importance of a good fit for flight safety and flight performance reasons is recommended. Providing the aircrew with a leaflet containing points of attention concerning their helmet fit might be helpful. These points of attention could include the correct manner to put on the helmet and checks aircrew can perform themselves such as the position and tightness of the nape and chin strap, the ear cup pressure, and the helmet stability:

> *The better the fit of the helmet, the less you will suffer from the weight. When the helmet is fixed on your head, it feels better; you still have to deal with the neck load, but it is more positive, the experience of the weight is more positive* [31].

Finally, for the next-generation cockpits, the need for a comfortable 'custom' fitted helmet arises from the fact that the NVG/HMD must remain securely in place, relative to the pilot's design eye point. These liners are manufactured from scans of the aircrew's head and conform to the topography of the wearer, resulting in a more stable and comfortable helmet. This is complementary to head tracking technology as it ensures that the precise head tracking function, whereby as the pilot turns his head the system computer recognises the new orientation and updates the visor display imagery. Form fit or custom fit liners are used in the Typhoon helmet and the Aircrew Protective Equipment and Detection (APED) helmet used by the UK.

5.4 NVG AND COUNTERBALANCE POLICY AND USAGE

Fast Jet (FJ), Rotary-Wing (RW), and Multi-Engine (ME) aircrew all use NVGs and some are now using HMDs. Despite NVGs being cited as a perceived causative factor in neck pain prevalence surveys, there is no consistent approach to guidance or policy for aircrew amongst the NATO countries (Table 5-1). The differences are most likely due to the ability and agility of the aircraft and how the individual countries balance risk against capability. The lack of guidance for RW aircrew is surprising given that aircrew report the use and duration of use of NVGs as the main perceived causative factor in neck pain [36].

Table 5-1: Guidance/Policy for NVG Use.

Country	Fast Jet Aircraft Guidance/Policy	Rotary-Wing / Multi-Engine Aircraft Guidance/Policy
United Kingdom	Release to Service (for Typhoon only) provides a warning to aircrew that "manoeuvres flown above 4 G with NVGs donned pose a significant increase in risk of neck injury" No restrictions on use of NVGs in other fast jet aircraft using NVGs	None
United States Navy	None (Hornet capable of +7.5 Gz)	None

Country	Fast Jet Aircraft Guidance/Policy	Rotary-Wing / Multi-Engine Aircraft Guidance/Policy
Finland	Maximum +6 Gz with NVG down locked Maximum +3 Gz with NVGs locked up No restrictions with other helmet-mounted displays	None
Belgium	No specific G limitations (at night they are not doing Basic Fighter Manoeuvres, so flights are usually limited from +5 to +6 Gz)	None
Netherlands	Flying with NVGs in the up position is restricted to +3 Gz	None
Germany	EUROFIGHTER (Air policing only): +4 Gz limit with NVGs in the up position and +6 Gz when lowered (due to the helmet limitations, not neck pain)	None
Italy	**AMX(AS)-1:** • +3 Gz limit with NVG fit and in up-locked position • +6 Gz limit with NVG fit and in down-locked position If conditions permit, NVGs shall be removed and placed clear of the escape path or, if possible, stowed before ejection **TORNADO-1:** • +3 Gz limit with NVG fit and in up-locked position • +6 Gz limit with NVG fit and in down-locked position **F-2000:** • +3 Gz limit with NVG fit and in up-locked position • +6 Gz limit with NVG fit and in down-locked position It is recommended to not exceed +4 Gz in down-locked position in order to minimise neck pain	None

5.4.1 Use and Choice of Counterweights

Many aircrew wear Counterweights (CWs) on their helmet in an attempt to counterbalance the load on the neck produced by NVGs or other helmet-mounted systems. In fact, after experiencing neck pain, aircrew may choose to reduce their CW while wearing NVGs [37]. Helicopter aircrew typically use CW attached to the rear of the helmet to reduce the neck fatigue caused by wearing NVGs, but also in some cases to prevent the helmet rotating and slipping forward on their head.

Current counterbalance systems are capable of providing a balanced helmet system in the static neutral position, but at the expense of increased helmet system mass and higher helmet system profile (i.e., weight and bulk of the helmet), thus applying more load on the neck and increasing the risk of neck injury. This problem is exacerbated when the helmet is not fitted properly. Counterweight as an engineering solution is only effective in a quasi-static neutral position, which is rare in aircraft operations.

Given that properly balanced counterweights (just enough to balance NVGs) are only beneficial in a quasi-static neutral posture, for now the amount of counterweight should not exceed the manufacturer's suggested limit. Therefore, other counterbalance solutions should be explored that do not add mass and inertia to the overall system balance on the head (see Helmet System Support Devices Section 5.8.1).

In a study carried out for the UK MOD, [38] aircrew were asked to identify their normally used CW. The standard issue 450 g and 600 g options were identified by aircrew, and in addition, a 300 g locally produced option by some aircrew. The Aviators' Night Vision Imaging System (ANVIS) battery box used in lieu of a CW weighed 214 g.

No link was found between the CW chosen and the mass of the NVGs used, with aircrew frequently choosing to add mass without regard for the weight of the NVG. The lightest NVG (NG2000) had the highest proportion of users with the heaviest CW, the next heaviest (ANVIS-9) had the highest proportion of users with the lowest CW. The proportions of users with 450 g and 600 g CWs for Nite-op and NG700 were very similar, despite the 60 g mass difference between the two NVGs.

The review of CW vs. NVG mass for aircrew was only carried out on a small population, therefore it was recommended that further work was required to understand the link between NVG mass, helmet mass and choice of CW due to the large range of head-borne mass between the lightest and heaviest combinations. This work is yet to be done; however, given the drive to reduce head-borne mass properties, the 500 g difference in NVG and CW combinations identified would result in a greater reduction than changes to any other part of the helmet system.

Current CW choice seems to be a personal choice, with little correlation between the mass of the CW used and the additional mass of the NVG. Aircrew appear to continue with the same CW even when they change helmet or NVG type. Keeping with the head-supported mass principles (Section 5.2), it is recommended that aircrew begin with the minimum CW mass that provides the closest helmet system CoM to the head. As they perform their flying tasks, they may want to adjust their CW to achieve the best counterbalance and comfort with as little mass as possible and likely there are differences in neck strength, pain, previous injury, size, and shape that affect CW preference.

5.5 IMPLICATIONS OF HEAD-SUPPORTED MASS – NEW FINDINGS

Understanding the link between HSM, neck pain, and injury is the topic of ongoing research in many countries. The following section summarises the work that has been undertaken.

5.5.1 US Army – Updates to the USAARL Curves

The Defense Healthcare Agency – Aircrew Mishap Prevention working group funded a project to update the USAARL Performance Decrement Curve [30] through 2019. The objective of the study is to assess a broad spectrum of helmet and helmet-mounted systems and expand the knowledge of the impact of HSM, vibration exposure, and duration of wear on multiple physiologic/biomechanical, kinematic, performance, and subjective measures. Neck pain as a quantifiable metric is difficult to assess in volunteer studies for various reasons, including human research volunteer protection regulations and ethics, variability in individual pain perception, truthfulness in responses due to concerns of repercussions or negative impact on job performance, and lack of an identifiable/standardisable 'pain' measure. A main aim of this study, therefore, is to identify which of a multitude of metrics might be the best correlate or surrogate for neck pain.

Product Manager, Air Warrior is pursuing modifications to the Army's primary rotary-wing helmet, the HGU-56/P. Among the modifications to the HGU-56/P is the capability of the helmet to accept newly emerging helmet tracker systems. Helmet tracking capabilities are being designed for implementation across the Army's utility and cargo helicopter fleets. In addition to increasing head-supported mass, the addition of helmet tracking systems to the HGU-56/P also shifts the helmet system's centre of mass rearward and upward, nearing the current limits for vertical and horizontal centre of mass locations.

The AIPH Health Hazard Assessment program issued a memorandum (Subject: U.S. Army Health Hazard Assessment Program-Advanced Technology Objective Requirements, 13b July 12). AIPH Priority #9 – Musculoskeletal Trauma (Head-Supported Mass) specifically requested research to, "Develop an integrated model to assess HSM risk, develop related medical injury criteria guidelines, and design standards for health hazard assessors and materiel developers." The existing HSM curves are limited in their ability to assess risk beyond the equipment norms of the time they were developed. Technology development and fielding has far surpassed the "worst case" scenario of that time with regard to mass and CoM offset. AIPH, NSRDEC, and PEO Soldier are unable to adequately assess the risk of newly developed technologies without updated realistic standards.

The existing USAARL curves were developed based on kinematic, performance, and physiologic response to HSM configurations with an upper limit of 83±23 N-cm established by Butler [39]. Modifications in helmet fit and design as well as vibration exposure, since the Butler study, may have improved tolerance to mass and CoM offset. Despite these potential improvements, operational requirements are dictating increased mass and CoM offsets outside of those previously established limits, and the kinematic, performance, and physiologic response to these mass and CoM changes must be determined.

5.5.2 UK Helmet Mass Properties to Minimise Musculoskeletal Injury

Musculoskeletal Injury (MSI) in UK military aircrew occurs at a rate above that observed in an equivalent general population. The prevalence rate of neck pain in the UK is reported as 70% in FJ aircrew, 57% in Rotary-Wing (RW) front aircrew, and 71% in air loadmasters [40]. The greater prevalence of neck pain in these aircrew tends to be associated with exposure to the high-G environment in fast jet platforms and the use of helmet-mounted equipment, particularly in non-neutral head positions, in rotary-wing platforms.

The MOD-funded Aircrew Systems Research programme aims to develop a tool that will help understand the impact of head mass, moment, movement, and environmental +Gz on the response of muscles that move and support the head for aircrew [41].

The SIMM musculoskeletal model was used to model the force response of 26 muscles located on the left side of the neck during head roll, pitch, and yaw as the model is symmetric. Each simulation was performed with different head mass properties: a mass increase up to 5 kg or a head CoM displacement up to ± 5 cm forward-backward, up-down or left-right. The effect of increasing acceleration up to +9 Gz was also investigated. The model output was evaluated to determine which muscles were sensitive to changes in mass properties and what level of force they generated. Subsequently using a 'helmet' segment modification to the model the utility of SIMM for comparing UK MOD helmets was investigated.

The key findings obtained from the results of this static assessment of isolated head movements were as follows:

- Neck extensor muscles are the most sensitive to changes in head mass, CoM, and +Gz under static conditions; in contrast neck flexors were insensitive to changes in mass properties.
- In most instances, pitch movements resulted in the highest muscle force production under static conditions.
- Under static conditions analysis revealed that a head-mounted mass of less than 2 kg will maintain muscle forces below maximal levels; however, although not directly determined in this work, this may not be the case if the CoM is not in the neutral position.
- Head-mounted masses with a CoM below or rearward of the neutral head CoM will lower the neck extensor force production.
- Of all the factors investigated, Gz has the greatest effect on the force response of the muscle. In the majority of sensitive muscles, forces reach maximal levels between +5 and +7 Gz without any additional helmet mass.

When the SIMM model was used to compare potential new aircrew helmets, the model revealed the heavier more balanced helmet elicited less muscle force than the lighter less balanced helmet during head pitch. These findings highlight the need for combinations of mass properties to be investigated.

This is the first step towards establishing a tool to understand the impact of head mass, moment, movement, and environmental Gz on the response of muscles that move and support the head for aircrew. The findings now have to be confirmed under the dynamic conditions representative of flights, with the model parameters representative of aircrew.

5.5.3 Canada – Neck-Supported Mass Properties, Joint Loading, and Muscle Activity

As in the UK, musculoskeletal injuries in Canadian military aircrew occur at a rate above that observed in an equivalent general population. Specifically in RCAF tactical helicopter aircrew community, both recent and historical survey data has shown that between 70 – 80% of aircrew report persistent neck pain that they directly attribute to flying [3], [6], [42]. This is not altogether unexpected considering a series of studies have shown that the in-service helmet system worn by RCAF tactical helicopter aircrew, consisting of a helmet, NVG, a battery pack, and a counterweight, can add up to an additional 2.5 kg of mass that must be supported by the neck [43]. Given that the commonly accepted mass of the human head is between 3.49 – 4.73 kg [44], the helmet system can effectively add an additional 53 – 72% more mass that the neck must ultimately support. Also, the tactical helicopter helmet system CoM may move by approximately 3 cm forward or aft of the head CoM [43].

Previous studies investigated the impact of head-supported mass properties on neck muscle activity while participants held static postures. This current study evaluated the impact of changes in mass, CoM, MoI, as well as dynamic movements, on neck loading and activity. That is, the purpose of this study was to determine the relative contribution of each mass property (total mass, CoM, and MoI) on neck joint loading and muscle activation. The mass conditions studied are summarized in Table 5-2.

The study was specifically designed to focus on a series of tasks identified as commonly performed by either tactical helicopter pilots or flight engineers *Outside Scan Regular* or *Equipment Handling Inside* [45]. Some tasks, such as *Walking*, were common to both types of aircrew.

Table 5-2: Mass Conditions Studied.

Condition	Mass (kg)	Centre of Mass Offset (cm)	Moment of Inertia (kg-cm^2)
1	1.9	0	350
2	1.9	0	450
3	1.9	0	550
4	1.9	-2	450
5	1.9	2	450
6	2.5	0	450
7	2.9	0	450

The study was a laboratory-based study using a simulated tactical helicopter "test bed" that included realistic aircraft seating and controls (cyclic, collective, and rudder pedals). A series of "targets" external to the cockpit were also marked in the laboratory to serve as desired eye points for simulated scanning tasks. The decision was made to limit the participants to those with healthy necks. A combination of demonstrated video by actual RCAF aircrew, expert instruction, and practice was used to ensure realistic task simulation.

A combination of optical motion capture, inverse dynamic modelling, and wireless electromyography were used in the experiment. Dependent measures included kinematic, kinetic, and Electromyography (EMG) data. For example, EMG of five neck muscles was collected bilaterally and both peak and average levels of activation were analysed. For the purposes of this section, only mean extensor moment of force about the C7-T1 joint, and mean erector spinae linearly enveloped EMG signal are reported.

A series of regression equations were derived with the intention of being used as predictors for estimating mean neck extension moment and mean EMG level of Sternocleidomastoid (SCM) activation (reported as percentage of maximum voluntary contraction). If an independent variable (mass, CoM, or MoI) in the experiment produced a significant change ($p < 0.05$) in one of the dependant variables (extension moment or SCM EMG), that independent variable was used as a predictor variable for the regression equations. This led to regression equations with only mass and MoI as predictors since CoM was not shown to have a significant effect.

Key points to take away from the Canadian Neck Supported Mass study are:

1) Overall, only mass and MoI contribute to extension moment. That is, as mass increases and MoI increases, the extension moment and muscle activity magnitude increase and therefore potentially increase the risk of injury. Mass and MoI were found to have a significant effect on extension moment.

2) MoI may have a relatively higher contribution for extension moment for FEs than pilots. This makes some logical sense given FE tasks are typically more dynamic as they are allowed to move within the cabin and lean out the side doors while the Pilot is constrained to movements within their chair.

3) The regression equations can be used to compare different helmet system configurations. For instance, helmet systems that have mass properties equivalent to conditions 1 and 7 yield an extension moment of 14.1 Nm and 15.9 Nm, respectively, from the regression equations. Although the difference is only 1.8 Nm, the cumulative effect of an additional 1.8 Nm may be significant over multiple missions leading to

significant flight-related neck pain. Thus, the helmet system with condition 1 mass properties would be the better choice in order to reduce the risk of developing or aggravating neck pain.

4) The regression equations do not indicate any mass property neck pain tolerance limit.

Nevertheless, this study serves as a model for future aircrew and occupations that must be performed while wearing a helmet system or large amount of neck supported mass. It is hoped to combine the results of the UK and Canadian studies so to increase the power of these analyses.

5.5.4 Head-Supported Mass Studies Summary

The UK and Canadian studies confirm that mass, CoM, and inertia influence neck compression and shear forces, and torque. In the UK study, more muscle activation was needed to compensate any mass and Gz increases and forward or rearward CoM. In the Canadian study, regression equations were generated between muscle moments or activation and total mass, CoM, and MoI. However, neither study was able to provide mass property limits because not enough is known about the chronic pain mechanism.

Determining the mass property limit would be a formidable, if not impossible task to derive experimentally. Theoretically, this would require a longitudinal study where aircrew are tracked over their career. The independent variables to be collected would need to be helmet system mass properties, aircrew tasks performed, as well as the exposure time (amount of time the helmet system is worn). The dependent variable would need to be aircrew neck pain incidents. With these data, one can begin to map out an injury mechanism space from which episodic and chronic neck pain limits could be derived. From Fraser et al. (2015), we know that chronic pain occurs somewhere between 100 and 200 NVG flight hours. As one could imagine, this longitudinal study would be a formidable undertaking, and unethical if the end point were to be episodic or chronic neck pain.

As an aside, acute injury mass property limits are more readily available because neck structure material properties are known and exposure times are in the order of seconds (i.e., impact forces). And, therefore, these limits are readily calculated or measured [46].

So, what's the alternative? Our postulate is still logically valid: reducing head-supported mass properties will reduce the risk of neck pain. And therefore, from a procurement perspective, a mandatory requirement for a new helmet system for all configurations should never exceed the mass properties of the current system. The acceptable helmet system would be one that matches or achieves even lower mass properties for a night configuration than the current-day configuration helmet system.

Once lighter, more balanced, and lower inertia helmets are put into operations, neck pain rates should be tracked over time. This would provide key data points to begin to map out the mass property limits for aircrew chronic pain.

5.6 INTEGRATION WITH BODY-BORNE EQUIPMENT

Merging equipment into an integrated system has the potential to influence performance, safety, and function. With increasing technologies, the body has become prime real estate for new equipment. Visual systems, communication systems, and navigation systems can all increase mission and operational performance. However, if the integration of the safety systems with these new systems is not considered in the design of all pieces of the system as a whole, the function, performance, and safety will be hindered. It is a constant requirement of military procurement authorities to maintain safety whilst improving capability. We have already shown that head-borne equipment added to the helmet system can cause increased forces on neck muscles [41], [47], [48]. The helmet and life preserver collars have interfered with head movements resulting in limiting field of view or forcing aircrew to adopt an unnatural posture for comfort and to get the extra range in motion needed to increase the field of view. Some life vest collars have then been streamlined to be thinner to reduce the interference between the helmet and vest; however, in so doing, there is now a concern that the bladders are not large enough to properly function. This means a reduction in the buoyancy of the aircrew below safe limits. The weight of the survival equipment kept within the vests can potentially put unwanted pressure on the shoulders and potentially the neck depending on the design. It is not just the weight of vest but also the shape of it. Some vests are collar-like (e.g., UK Typhoon vest) and others have sleeves up to shoulder line. The former model increases the pressure in cervical/thoracic line and may also increase loading in the neck due to flexed position, the latter one (like FIN Hornet-vest) spreads pressure on shoulders. The added pressure may negatively influence the posture of aircrew during flight, causing them to slouch forward thus causing a non-neutral head/helmet posture and therefore increasing neck loads. Over time, the non-ideal postures can lead to musculoskeletal trouble. In the same fashion, if the equipment is too thick or bulky in the upper back and neck area, aircrew posture will again be influenced negatively.

5.7 IMPROVED SYSTEM DESIGN

Helmet system designers will need to find ways of optimising (minimising) overall helmet system mass properties while maintaining capability and impact protection. This can be achieved through a systematic weight reduction of all components, whilst also improving fit and stability (reducing the need for counterweights). In addition, better platform integration of equipment to support augmented vision and imagery/symbology systems can reduce the amount of equipment mounted to the helmet system.

5.7.1 UK Example of System Design

In late 2009 the UK MOD embarked on a project to rapidly develop and field a new helicopter aircrew helmet. Key requirements for the helmet were:

- Compliance with UK-specific impact protection and crash safety requirements;
- Good comfort and stability;
- Lightweight and good centre of mass;
- Integration with two different UK NVG types;
- Integration and clearance onto three helicopter platforms; and
- An in-service date of Spring 2012.

The helmet was developed by a small company based in the US and the project was managed by MOD Defence Equipment and Support. The team consisted of MOD procurement, an aeromedical advisor, end users (aircrew). the contractor, and Subject Matter Experts (SMEs); specialists in requirements for the helmet, integration with other existing aircrew equipment, platform integration, flight clearance, assessment/testing, and airworthiness requirements. The project took a concept and brought the helmet into service in 2.5 years, meeting all the key requirements. The equipment was received well by the aircrew that use it. The success of the project is considered to be the result of the close working relationship of the multidisciplinary team and the breadth of expertise involved, which allowed the initial requirements to be clearly defined, possible issues to be aired and resolved during the design process. A rapid test/fix/test cycle, which involved the whole team, during the test and qualification phase allowed problems to be well understood and resolved quickly. Following service introduction user feedback was sought to determine the need to fix issues in-service, and a number of improvements were rapidly fielded.

5.7.2 Wider Head-Borne System Considerations

We know NVGs are currently fundamental to the way military aviators operate. However, whilst the systems clearly offer capability advantage, they come with limitations. NVGs typically have a field of view of around 40° and HMDs have a typical field of view of between 20° for a monocular sighting system to 40° binocular for night vision or image sensor delivery display. These limitations drive head movement. With improved field of view, head movement could potentially be reduced.

The primary use of HMDs is to continue to have enhanced vision as well as instrumentation and symbology when looking off-bore sight. For example, designating an off-axis target under high G with an HMD is faster than with a Heads-Up Display (HUD), requires less aircraft movement, and thus less G exposure. However, this advantage can be lost when a target must be maintained under manoeuvre. HMDs add weight, bulk, and require more muscle force to operate.

As technology matures, there is a drive to move to more digital/integrated systems which can lead to better integrated and potentially lighter systems. Careful design will be required to ensure that mass savings are not replaced with new equipment and that the CoM is managed. In addition, as the capabilities of these systems are still being explored and have not yet reached their full potential so the influence on neck pain should be considered as their use is being developed.

As an example of the impact of the introduction of a new capability, the Royal Danish Air Force F-16 pilots implemented the Joint Helmet-Mounted Cuing System (JHMCS). After this, 97% of pilots reported neck pain, and half of these pilots used JHMCS regularly [20]. As well as the increased mass and modified CoM, the HMD changes the behaviour of the pilot. A pilot's head should remain stationary in a neutral position when pulling +Gz. However, this posture is not conducive for 'checking six' or taking full advantage of the JHMCS capability which allows for off-bore site targeting especially during +Gz manoeuvres. This postural change under G will also aggravate the situation.

5.8 POTENTIAL PHYSICAL MITIGATIONS

Whilst making improvements to the helmet system itself are the best option overall, consideration has been given to whether there are any interim measures that can improve conditions for operators. The next sections will look at some of those options that have been considered.

5.8.1 Helmet System Support Devices

Current counterbalance systems only add to the weight and bulk of the helmet, thus applying more load and increasing neck injury. Helmet System Support Devices use either neck supports or spring forces (rather than gravitational forces) to provide an opposing force to NVGs, thus effectively balancing the helmet system in both static neutral and non-neutral postures as well as dynamic movements. The Canadian neck pain mitigation project explored a number of concepts: neck supports and braces, spring device, and chin rest. While some of the concepts showed a decrease in neck loading and muscle activation [49], all of them have significant operational and airworthiness challenges.

5.8.1.1 Spring Device

Counterweight provides a counterbalance when NVGs are used. However, this counterbalance is most effective only in a quasi-static head and eyes forward posture. In all other postures and dynamic movements, CW adds mass and inertia to the already heavy helmet. Conceptually, a mechanical spring may do the same job as counterweights without adding as much mass to the helmet system. A number of prototypes were designed based on this concept where the spring device was mounted on the back of the helmet and attached to the Life Preserver Survival Vest as shown in Figure 5-4 [43]. A laboratory study showed that this system afforded less muscle activity (i.e., reduced % MVC) when implemented.

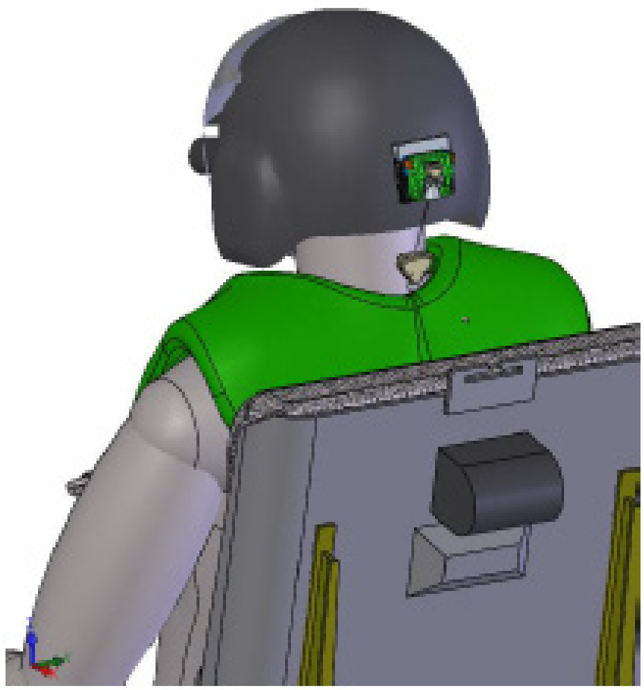

Figure 5-4: Spring Device from Thumbprint / Queen's University.

This system had shown promise in ground testing, but pilot and aircrew feedback from a flight trial in a Griffon helicopter revealed that during the more dynamic postures in flight the spring system becomes a hindrance and forces the aircrew member to exert more neck twist. Emergency egress for the pilots would also be an issue with this system [50]. The challenge is that any device that supports the helmet to reduce or offset the weight must not compromise neck mobility, posture, crashworthiness, or egress. Following this work, Canadian research focus has shifted to develop future helmet system designs that meet these operational requirements.

5.8.1.2 Foam Wedge

The USAF investigated the use of a foam wedge as a possible way to counteract the helmet system mass properties [51]. A prototype foam wedge to mitigate poor balanced HSM has been investigated by the USAF School of Aerospace Medicine and DRDC. The foam wedge (Figure 5-5) is positioned under the chin and attached to the chest area using Velcro. An initial study has been conducted to determine the tolerability of a foam wedge and any interference to cockpit duties during 1-G flight [51]. Four subjects (two male, two female) performed various cockpit activities in 5-minute intervals for 45 minutes. They wore a helmet-mounted display mass mock-up helmet with an MBU-20/P mask while strapped into an advanced concept ejection seat allowing for the seatback angle to be reclined to both 8° and 30°. Following testing, each participant completed a qualitative questionnaire regarding comfort, fit, and feasibility of the foam wedge device using a 1 through 10 scale. The initial study reported neck discomfort was less with the wedge and that the wedge did not impede normal cockpit activities. Further investigation with a control group into the foam wedge's neck pain mitigation performance is planned.

Figure 5-5: Subject Wearing the Foam Wedge to Support the Chin, to Offset the Forward Centre of Balance. Photos reprinted with permission from W. Dodson.

5.9 RECOMMENDATIONS

This chapter has highlighted five key design principles that should reduce the risk of neck pain:

- Reduce helmet system mass;
- Improve helmet system mass properties to achieve better balance;
- Lower helmet system inertia, volume, profile, or bulk;
- Achieve a proper helmet fit; and
- Good integration with below-neck equipment needs to be achieved.

Ideally, a systems design approach should be considered with respect to the all body-borne equipment and their integration within the aircraft workspace. But given that this approach is not always possible, various components may be designed to reduce mass and inertia. In particular, the helmet, NVGs, battery pack, and counterweights may be designed to reduce mass and inertia independent of each other. Furthermore, there are certain helmet designs that may make it easier to fit the helmet. Also, the helmet can be shaped at the back in order to accommodate a range of vests, or the vest can be shaped to accommodate a range of helmet types.

Recommendation 5.1 (Sections 5.2, 5.3, and 5.6): New helmet system procurement and design should ensure that the five key design principles – reduce helmet system mass, improve helmet system mass properties to achieve better balance, lower helmet system inertia, volume, profile, or bulk, achieve proper helmet fit, and ensure appropriate integration of helmet system with the rest of the ensemble – are considered in any procurement of a new system, thus considering the helmet system as a whole.

Recommendation 5.2 (Section 5.3): Aviation Life Support Equipment (ALSE) fit procedures should be reviewed and followed regularly to ensure that fitting is optimised.

Recommendation 5.3 (Sections 5.3 and 5.4): A proper helmet fit should be done during the initial fitting, whenever there is a change to the helmet system configuration, and at regular intervals. A proper helmet fit will decrease any slippage on the head (as well as reduce hot spots and pressure points, and increase comfort), and therefore reduce the amount of CW required for stability.

Recommendation 5.4 (Section 5.4): Given a proper helmet fit, the minimum Counterweight (CW) mass should be used that improves the stability and balance on the head. Counterbalance use for all aircrew should be reviewed when fit is assessed to ensure most appropriate CW is being used.

Recommendation 5.5 (Section 5.6): New helmet system procurement and design should take into account aircrew behaviours, tasks, postures, postural sequences, and physical movements (see Chapter 6 for more information).

Recommendation 5.6 (Section 5.6): New helmet system procurement and design should consider the integration of the new helmet system within the ALSE system, such as vests and G protection systems, as well as the cockpit and cabin (e.g., field of view constraints or affordances due to the head-borne equipment).

Recommendation 5.7 (Section 5.7): New helmet system procurement and design must consider all system requirements as shown in Figure 5-1, such as impact protection.

Future work includes:

- Continue to rank helmet systems on USAARL-like curves;
- Introduce the mass moment of inertia dimension to the USAARL curves;
- Employ model development and integration to better understand helmet system fundamental issues towards developing evidence-based product specifications; and
- Continue to study the interaction between helmet fit and CW and its impact on neck loading, CoM, stability, and neck pain in order to formulate effective guidance on CW usage.

5.10 REFERENCES

[1] Rash, C.E. (1999). Helmet mounted displays: Design issues for rotary-wing aircraft. Bellingham, WA: SPIE Press.

[2] Rash, C.E., Russo, M.B., Letowski, T.R., and Schmeisser, E.T. (2009). Helmet-mounted displays: Sensation, perception and cognition issues. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

[3] Chafé, G.S., and Farrell, P.S.E. (2016). Royal Canadian Air Force CH-146 Griffon aircrew 2014 spinal musculoskeletal trouble survey. Toronto, Canada: Scientific Report, DRDC-RDDC-2016-R179, Defence Research and Development Canada, Toronto, Canada.

[4] Fraser, W.D., Crowley, J.S., Shender, B.S., and Lee, V.M. (2015). Multinational survey of neck pain in rotor-wing aircrew (p. 24). TTCP Technical Report DOC-HUM-01-2015: The Technical Cooperation Program.

[5] Harrison, M.F., Coffey, B., Albert, W.J., and Fischer, S.L. (2015). Night vision goggle-induced neck pain in military helicopter aircrew: A literature review. Aerospace Medicine and Human Performance, 86(1), 46-55.

[6] Karakolis, T., Farrell, P., and Fusina, G. (2015). Neck overuse injury in CH-146 Griffon helicopter aircrews. Procedia Manufacturing., 3:4205-4212. doi: 10.1016/j.promfg.2015.07.396.

[7] Farrell, P.S.E., Shender, B.S., and Fusina, G. (2018). The use of models in aircrew neck trouble research. Toronto, Canada: DRDC-RDDC-2018-R147, Defence Research and Development Canada.

[8] Froom, P., Froom, J., Van Dyk, D., Caine, Y., Ribak, J., Margaliot, S., and Floman, Y. (1984). Lytic spondylolisthesis in helicopter pilots. Aviat Space Environ Med, 55(6), 556-557.

[9] Hamalainen, O., Toivakka-Hamalainen, S.K., and Kuronen, P. (1999). +Gz associated stenosis of the cervical spinal canal in fighter pilots. Aviat Space Environ Med, 70(4), 330-334.

[10] Hamalainen, O., Vanharanta, H., Hupli, M., Karhu, M., Kuronen, P., and Kinnunen, H. (1996). Spinal shrinkage due to +Gz forces. Aviat Space Environ Med, 67(7), 659-661.

[11] Hodgdon, J.A., Pozos, R.S., Feith, S.J., and Cohen, B.S. (1997). Neck and back strain profiles of rotary-wing female pilots. In: NHR Center (Ed.). San Diego, CA: NTIS ADA327485, U.S. Army Medical Research and Materiel Command.

[12] Landau, D.A., Chapnick, L., Yoffe, N., Azaria, B., Goldstein, L., and Atar, E. (2006). Cervical and lumbar MRI findings in aviators as a function of aircraft type. Aviat Space Environ Med, 77(11), 1158-1161.

[13] Orsello, C.A., Phillips, A.S., and Rice, G.M. (2013). Height and in-flight low back pain association among military helicopter pilots. Aviat Space Environ Med, 84(1), 32-37.

[14] Shanahan, D.F., Mastroianni, G.R., and Reading, T.E. (1985). Back discomfort in U.S. Army helicopter aircrew members. Paper presented at the Aeromedical Panel Specialist meeting AGARD-CP-378, AD-A171 226, Pozzuoli, Italy.

[15] Äng, B.O., and Harms-Ringdahl, K. (2006). Neck pain and related disability in helicopter pilots: A survey of prevalence and risk factors. Aviation, Space, and Environmental Medicine, 77(7), 713-719.

[16] Greeves, J., and Wickes, S. (2008). Review of the United Kingdom National Work Programme on the long-term effects of sustained high G on the cervical spine. NATO RTO Review of National Work Programmes on the Long-Term Effects of Sustained High G on the Cervical Spine. Neuilly sur Seine, France: NATO.

[17] Hiatt, K., and Rash, C.E. (2011). The reported incidence of man-machine interface issues in army aviators using the Aviator's Night Vision System (ANVIS) in a combat theatre. Paper presented at the International Society for Optical Engineering, San Diego, CA.

[18] Smith, A.M. (2016). The prevalence and operational significance of neck pain and back pain in Air Combat Group: IAM-2016-003-CR, Institute of Aviation Medicine – Adelaide, Adelaide, Australia.

[19] Wickes, S.J., and Greeves, J.P. (2006). Occupation and lifesyle contributors to flight-related neck pain. Aviation Space and Environmental Medicine, 77(3), 199.

[20] Lange, B., Torp-Svendsen, J., and Toft, P. (2011). Neck pain among fighter pilots after the introduction of the JHMCS helmet and NVG in their environment. Aviat Space Environ Med, 82(5), 559-563.

[21] Thoolen, S.J., and van den Oord, M.H. (2015). Modern air combat developments and their influence on neck and back pain in F-16 pilots. Aerosp Med Hum Perform, 86(11), 936-941. doi: 10.3357/AMHP.4303.2015.

[22] Gallagher, H.L., Caldwell, E., and Albery, C.B. (2008). Neck muscle fatigue resulting from prolonged wear of weighted helmets. (AFRL-RH-WP-TR-2008-0096). Dayton, OH: Wright-Patterson Air Force Base.

[23] Barker, D.J., and Albery, C.B. (2010). Neck fatigue and comfort effects due to the extended wear of law enforcement representative head-borne personal protective equipment. (ECBC-TR-825). Waltham, MA: U.S. Army RDECOM Laboratory.

[24] Hamalainen, O. (1993). Flight helmet weight, +Gz forces, and neck muscle strain. Aviat Space Environ Med, 64(1), 55-57.

[25] Eveland, E., Goodyear, C., Shouse, C., and Esken, B. (2008). Human performance with helmet-mounted systems: The role of helmet configuration and mission duration. Aviat Space Environ Med, 79, 223-224.

[26] Pousette, M.W., Lo Martire, R., Linder, J., Kristoffersson, M., and Ang, B.O. (2016). Neck muscle strain in air force pilots wearing night vision goggles. Aerosp Med Hum Perform, 87(11), 928-932. doi: 10.3357/AMHP.4579.2016.

[27] Mathys, R., and Ferguson, S.J. (2012). Simulation of the effects of different pilot helmets on neck loading during air combat. J Biomech, 45(14), 2362-2367. doi: 10.1016/j.jbiomech.2012.07.014.

[28] Harrison, M.F., Forde, K.A., Albert, W.J., Croll, J.C., and Neary, J.P. (2016). Posture and helmet load influences on neck muscle activation. Aerospace Medicine and Human Performance, 87(1), 48-53.

[29] Harrison, M.F., Neary, J.P., Albert, W.J., Veillette, D.W., McKenzie, N.P., and Croll, J.C. (2007). Physiological effects of night vision goggle counterweights on neck musculature of military helicopter pilots. Military Medicine, 172, 8:864.

[30] McEntire, B.J., and Shanahan, D.F. (1998). Mass requirements for helicopter aircrew helmets. Fort Rucker, AL: Report 98-14, ADA 339781, US Army Aeromedical Research Laboratory.

[31] van den Oord, M.H.A.H., Frings-Dresen, M.H.W., and Sluiter, J.K. (2012). Optimal helmet use and adjustments with respect to neck load: The experience of military helicopter aircrew. International Journal of Industrial Ergonomics, 43, 73-79.

[32] van den Oord, M.H.A.H., Steinman, Y., Sluiter, J.K., and Frings-Dresen, M.H.W. (2012). The effect of an optimised helmet fit on neck load and neck pain during military helicopter flights. Applied Ergonomics, 43(5), 958-964.

[33] Forde, K.A., Albert, W.J., Harrison, M.F., Neary, J.P., Croll, J., and Callaghan, J.P. (2011). Neck loads and posture exposure of helicopter pilots during simulated day and night flights. International Journal of Industrial Ergonomics, 41(2011), 128-135.

[34] Thuresson, M., Äng, B., Linder, J., and Harms-Ringdahlab, K. (2005). Mechanical load and EMG activity in the neck induced by different head-worn equipment and neck postures. International Journal of Industrial Ergonomics, 35(1), 13-18.

[35] van den Oord, M.H.A.H. (2012). Prevention of flight-related neck pain in military aircrew. (Doctor of Philosophy), University of Amsterdam, Amsterdam, the Netherlands. ISBN 978-90-804423-0-6.

[36] Parker, P.K., and Meeks, C.B. (2013). Aircrew helmet mass briefing paper. UK: QINETIQ/13/00452/1, QinetiQ.

[37] Farrell, P.S.E., Maceda, E., and Niri, A. (2018). Correlating helmet system mass properties with pain levels towards helicopter aircrew neck-trouble mitigating solutions. Paper presented at the HFES 2018 Annual Meeting, Philadelphia, PA.

[38] Longman, P.J., Hudson, C., Grimshaw, T.L., and Bigmore, D.J. (2012). Optimisation of NVG training and maintenance for aircrew and survival equipment fitters. QINETIQ/12/00137/2, Farnborough, UK.

[39] Butler, B.P. (1992). Helmeted head and neck dynamics under whole-body vibration. PhD Dissertation, University of Michigan, Ann Arbor, MI.

[40] NATO. (1999). North Atlantic Treaty Organization (NATO): Cervical spine injury from repeated exposure to sustained acceleration. RTO-TR-4 AC/323(HFM)TP/9, France.

[41] Pollock, R., Puxley, K., and Llewellyn, M. (2017). An investigation of a software for interactive musculoskeletal modelling (SIMM) methodology to assess muscle force output in response to variations in helmet mass properties and Gz. UK: QINETIQ/17/00044, QINETIQ.

[42] Adam, J. (2004). Results of NVG-induced neck strain questionnaire study in CH-146 Griffon aircrew (p. 95). Toronto, Canada: Technical Report DRDC Toronto TR 2004-153 Defence Research and Development Canada, Toronto Research Centre.

[43] Fischer, S., Stevenson, J., Reid, S., and Hetzer, M. (2014). Spring-based helmet system support prototype to address aircrew neck strain (p. 95). Toronto, Canada: Scientific Authority: Philip S.E. Farrell, DRDC-RDDC-2014-C187, Defence Research and Development Canada.

[44] Yoganandan, N., Pintar, F.A., Zhang, J., and Baisden, J.L. (2009). Physical properties of the human head: Mass, center of gravity and moment of inertia. J Biomech, 42(9), 1177-1192. doi: 10.1016/j.jbiomech.2009.03.029.

[45] Tack, D.W., Bray-Miners, J., Nakaza, E.T., Osborne, A., and Mangan, B. (2014). Griffon Helicopter Neck Strain Project. Part 1: Mission function task analysis and physical demands analysis report. Part 2: Physical Demands analysis library. (p. 340). Toronto, Canada: Scientific Authority: Philip S.E. Farrell, Ph.D., DRDC-RDDC-2014-C228, Defence Research and Development Canada.

[46] Blackmore, M.E., Goswami, T., and Chancey, C. (2012). Cervical spinal injuries and risk assessment. In: T. Goswami (Ed.), Injury and Skeletal Biomechanics (p. 18). online: InTech.

[47] Farrell, P.S.E., Maceda, E., Niri, A., Apostoli, C., McGuinness, C., Valikanthan, J., and Karokolis, T. (2018). Helmet systems comparisons using neck muscle activity and external load measurements: Helmet systems assessment trial. Toronto, Canada: DRDC-RDDC-2018-R163, Defence Research and Development Canada.

[48] Llewellyn, M.G.A., Longman, P., Marston, P., and Barker, N. (2010). Prevention of musculo-skeletal injury – Observational task analysis to reduce the risk fo MSI in RW and ME aircrew. UK: QinetiQ.

[49] Dibblee, J., Worthy, P., Farrell, P.S.E., Hetzler, M., Reid, S., Stevenson, J., and Fischer, S.L. (2015). Evaluating a prototype device designed to alleviate night vision goggle induced neck strain among military personnel. Ergonomics, 58(12), 2067-2077.

[50] Fusina, G., and Karakolis, T. (2018). A pilot test of a method for assessing perceived neck muscle load by flight helmets: Reference Document, DRDC-RDDC-2018-D106, Defence Research and Development Canada, Toronto, Canada.

[51] Fischer, A.M., Dodson, W.W., Buhrman, J.R., and Eveland, E.S. (2017). Pilot study: Foam wedge chin support static tolerance testing. (AFRL-SA-WP-SR-2017-0026). Dayton, OH: Wright-Patterson Air Force Base: United States Air Force.

Chapter 6 – NECK PAIN PREVENTION AND MANAGEMENT – AIRCREW BEHAVIOURS

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6.1 INTRODUCTION

Workplace injuries often result from physical capabilities of individuals (or lack thereof), their tasks and behaviours, the workspace ergonomics, any protective equipment, and the external environment and there is no simple way to separate these factors (see Section 1.2). This is also true for aviation environment.

From Section 1.2 and Annex C, Aircrew Behaviours are one of five possible causal factors that contribute to neck pain, and for this discussion is defined as the conscious or non-conscious physical movements and postures that aircrew adopt to perform their tasks. Like the other factors, Aircrew Behaviours alone do not cause chronic neck pain; however, when combined with Body-Borne Equipment, Aircraft Workspace, and Organisational factors, Aircrew Behaviours may exacerbate aircrew neck pain. That is, the combination of non-neutral postures (behaviours), sometimes generated by poor ergonomics, along with additional G and vibration (workspace), or holding a poor posture over the course of a long mission (organisation), while supporting heavy, unbalanced helmets (equipment) can increase the risk of neck pain. While extreme postures (e.g., Check Slung Loads or Check 'six') may seem to be a significant contributor to neck pain, the frequency of these postures over the course of a multi-hour mission is also important to note. Extreme postures may, however, initiate an acute injury or aggravate an existing one, and so they should also be avoided whenever possible. Thus, solutions that promote biomechanically advantageous postures (i.e., more neutral positions or "naturalistic" postures) need to be investigated to determine whether they reduce the risk of neck pain.

A nonlinear interaction exists between Aircrew Behaviours and Body-Borne Equipment, and Aircrew Behaviours and Aircraft Workspace factors. That is, for a given aircrew task, if one were to make the helmet system mass properties worse, then there would be an increase in neck loads. However, aircrew may sense an increase neck loading and may change their posture to reduce the new neck loading (e.g., rotate the trunk rather than the neck).

Workspace ergonomics may force aircrew into sub-optimal positions such as 'helo-hunch' where helicopter aircrew are sometimes forced into a slightly bent forward position, with their neck extended due to the position of instruments and the angle of the seat, or a downward head rotation to observe the centre console display. These awkward postures increase neck loading [1]. The pilot may behave in a way to alleviate any neck discomfort by assuming a more neutral position for a few minutes to relieve neck loads and recover fatigued muscles.

The above examples show how aircrew might mitigate neck pain in response to increased head-supported mass and poor workspace ergonomics solely by changing their behaviours. Nevertheless, there are a few strategies that are not necessarily linked to body borne equipment (Chapter 5) or aircraft workspace (Chapter 7), but are related to how tasks are performed. These more advantageous aircrew behaviours are the subject of this chapter.

This chapter discusses the need for analysing aircrew behaviours (i.e., task analysis) to ultimately find ways to reduce the impact of tasks and postures on neck pain. Task analysis modelling is introduced in Section 3.1.1.7

and the results of the modelling activity are described herein. The chapter summarises the Canadian and UK task analysis studies that led to solutions that promote biomechanically advantageous postures.

6.2 AIRCREW TASK ANALYSIS STUDIES

Canadian and UK aircrew task analysis studies were conducted to understand the impact of tasks, postures, and dynamic movements on neck loads and MSI risk amongst rotary-wing aircrew. Task and physical demand analyses were used to identify, assess, and ultimately recommend neck pain mitigating solutions. Aircrew tasks and associated postural sequences were captured by operator interviews, video recording and observations in flight, as well as using motion capture systems to recreate and reproduce movements in the laboratory and in modelling and simulation. Task data were analysed to document the posture or postural sequence(s) needed to perform the task, as well as task frequency, duration, and potential MSI risk when performing the task.

6.2.1 Estimating Griffon Aircrew Neck Loads Using Task and Physical Demands Analyses

A new technique was developed to not only analyse aircrew tasks but also link those tasks to neck loading. The technique combines Mission Function Task Analysis (MFTA) and Physical Demands Analysis (PDA), which produces an Integrated MFTA/PDA Model (IMPM) of human work [2], [3], [4], [5].

MFTAs, which are typically cognitive focussed, help characterise the activities or tasks a worker (or a team of workers) must do to accomplish their job (or over a course of a mission). The result of the analysis is a relational database of tasks and subtasks, their timings, and prescribed rules for task sequencing; in effect this yields a model of human work. These task data are usually collected through interview and observation. Typically, information needs, attention demands, and other cognitive attributes are associated with the tasks and subtasks. The tasks are then reconstructed and various workload, attention demands, or other cognitive analyses are conducted to represent the course of the job and mission.

PDAs are physically focussed where one or two repetitive tasks are analysed to characterise the intensity, duration, and frequency of physical loads exerted on the worker's body or that the worker exerts on their workspace [6], [7], [8]. While physical loading data are typically collected through interviews, observations, and sometimes simple force measurements and calculations, this study captured joint angles using motion capture techniques as tasks were performed as shown, for example, in Figure 6-1. Time-varying joint angle data were used by the Visual 3D biomechanical model to calculate and estimate joint loads (compression forces, shear forces, and torques) intensity, duration, and frequency (if the loading was cyclical) on joint structures and for each task. Figure 6-2 is an example of this for the "Scan slung load" task. The estimated joint load intensity, duration, and frequency became physical attributes associated with that task. Thus, these attributes may be added to the associated MFTA tasks, which results in a model that has the potential to characterise both the cognitive and physical aspects of human work.

A load profile for a complete mission is derived by reconstituting the tasks (and thus the loads) as would be done for an MFTA operational sequence diagram. For example, Figure 6-3 shows the cumulative torque for an FE and for a slung load training mission both during the day and at night.

Figure 6-4, Figure 6-5, and Figure 6-6 show the cumulative Compression Force, Shear Force, and Torque, respectively, for a Logistics mission (Vignette 1) and Training Mission (Vignette 2), Day (orange) and Night (blue), and aircrew role (Flying Pilot (FP), Non-Flying Pilot (NFP), and Flight Engineer (FE)).

Figure 6-1: "Scan Slung Load" Task Showing FE Posture at Three Time Intervals. Orange motion capture sensor mounted on helmet is one of seven motion capture sensors worn by the participant. Photos reprinted with permission from DRDC Toronto Research Centre [3].

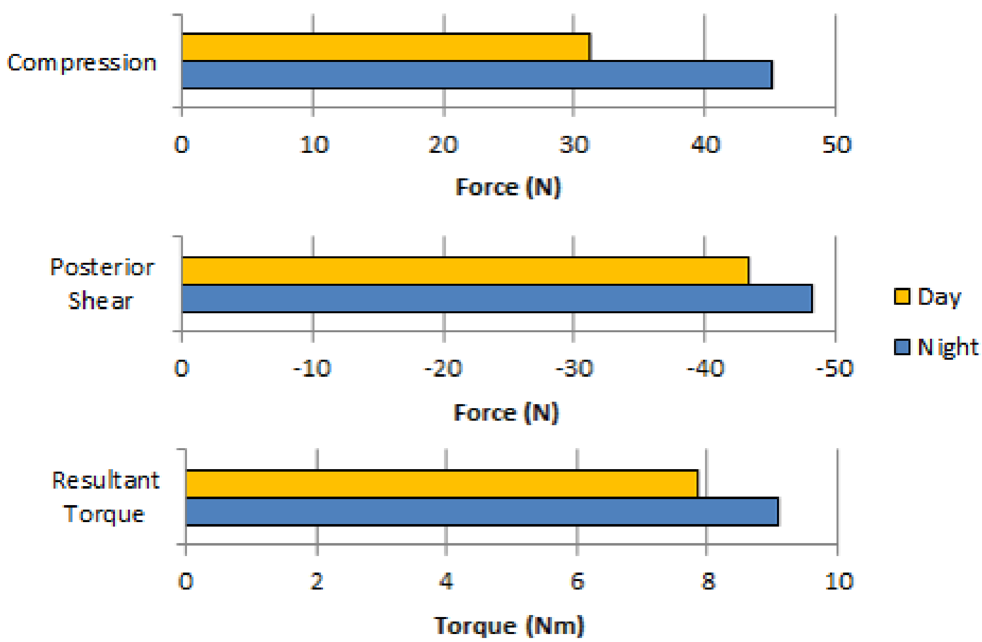


Figure 6-2: FE Neck Forces and Torques at C7/T1 for "Scan Slung Load" Task (without and with NVGs, i.e., day and night).

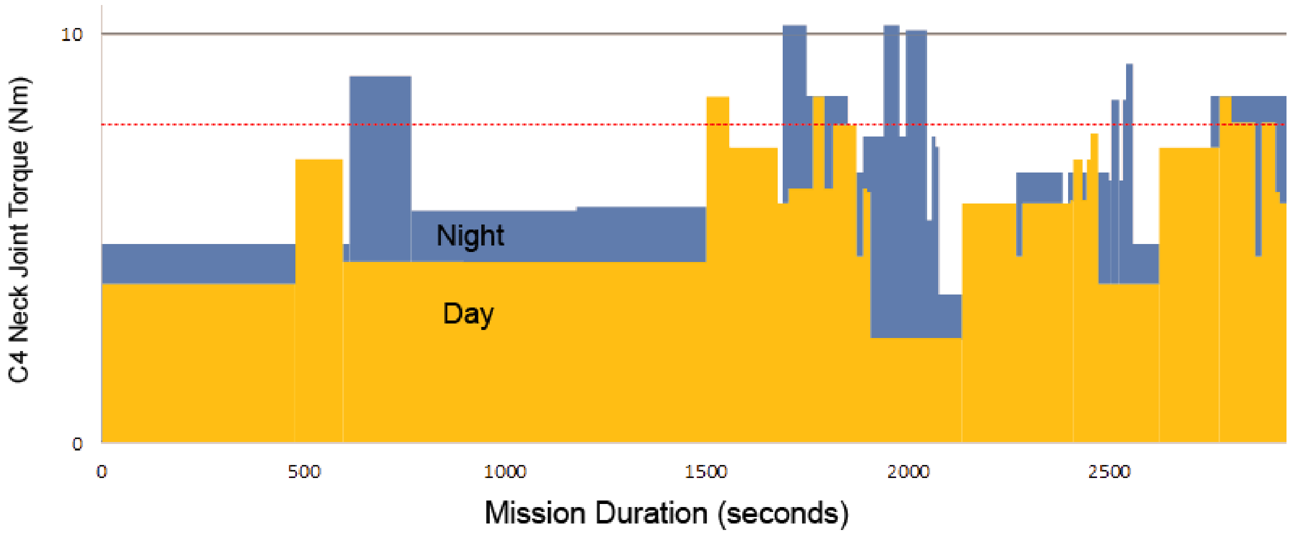


Figure 6-3: FE Resultant Neck Torque – Slung Load Training Mission (With and Without NVG).

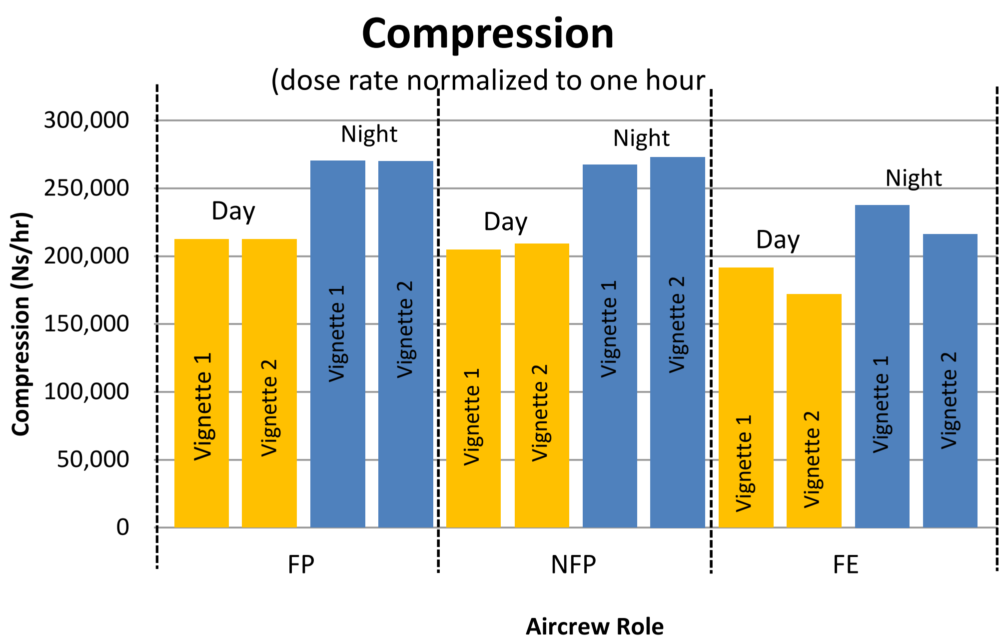


Figure 6-4: Neck Compression – Hourly Dose Rate Normalised Between Missions.

In Figure 6-4, both Pilots have higher compression forces than the FE across vignettes and day or night. In Figure 6-5, NFP has slightly higher shear forces than FP, likely due to the head-down and rotated position needed when operating the centre console Control Display Unit (CDU). The FE has significant shear forces due to the extreme positions they must strike to perform certain tasks such as Scan Slung Load. The neck torque, in Figure 6-6, has a similar pattern to the shear force in that over the course of the mission, the cumulative FE neck torque is higher than the NFP which is slightly higher than the FP. Torque is not only related to non-neutral postures but also dynamic movements [9]. Thus, if aircrew were to maintain a more **biomechanically neutral position** with **slower movements** while performing their tasks, this would reduce the neck torque (and shear force).

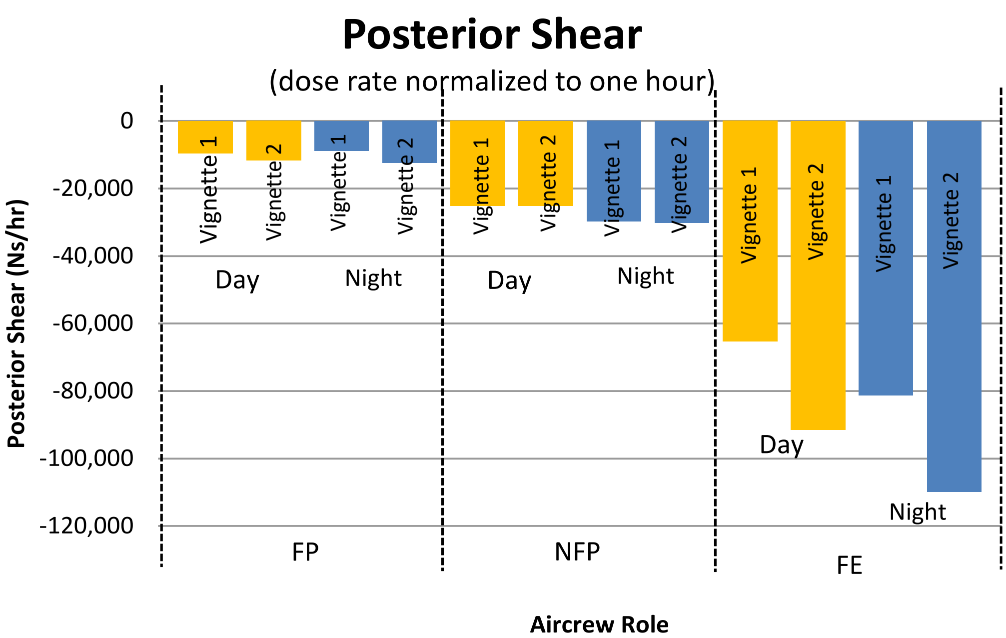


Figure 6-5: Neck Posterior Shear – Hourly Dose Rate Normalised Between Missions.

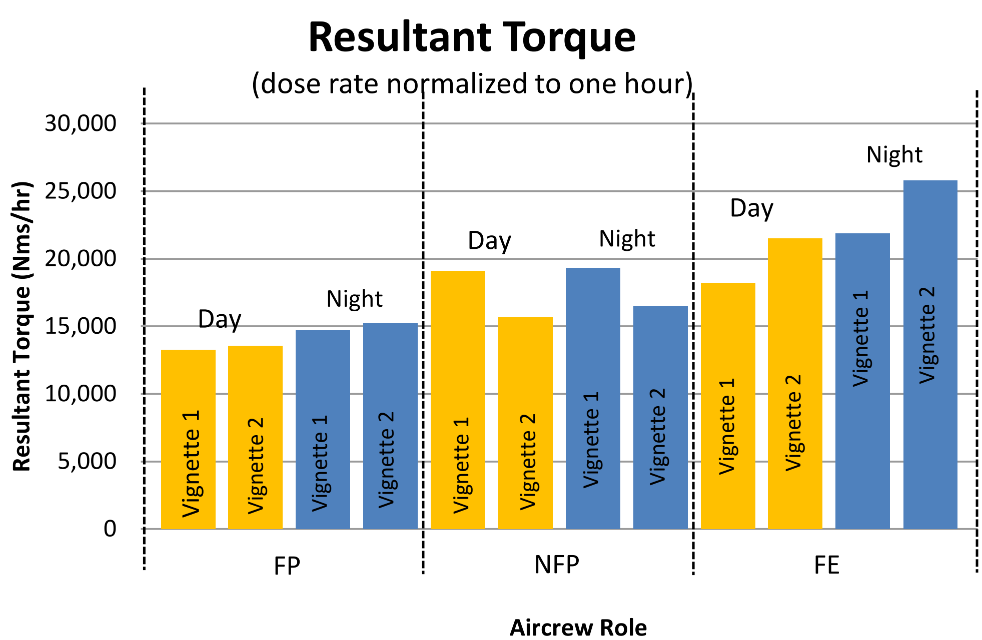


Figure 6-6: Neck Resultant Torque – Hourly Dose Rate Normalised Between Missions.

Note that the neck loads are relatively the same across missions except for FEs across all three loads, and NFPs for shear force. For the FE, while the Logistics Mission yields higher compression forces than during the Training Mission, the Training Mission yields higher shear forces and torques than the Logistics Mission. This make sense since FEs usually need to pay attention to what the student is doing while performing all the normal duties to ensure the safety of the aircraft. A potential (organisational) solution for the FE would be to minimise inflight night time training by incorporating some proportion of simulator and on-the-ground training (without using NVGs and CWs), or schedule training with longer intervals between night flights so that muscles are able to recover (i.e., optimal or Smart Scheduling).

For the NFP, cumulative neck torque seems to be an issue during the Logistics Mission where the NFP must operate the CDU (located on the centre console between the two seats) much more than during the Slung Load Training Mission. Holding a head-down and twisted position for several minutes at a time during a typical 2.5-hour mission places significant pressure on neck structures. A solution for this situation is **Task Sharing**. This solution is only viable for a two-pilot aircrew, where the FP and NFP change roles every 20 minutes or so.

In summary, MFTA and PDA analyses were performed for the three roles of the CH-146 Griffon aircrew, which allowed us to calculate/estimate cumulative neck loads across Logistics and Training missions. Several solutions were proposed that would reduce neck loads, namely: biomechanically advantageous positions, and task sharing (for multi-pilot aircraft only; a form of optimal scheduling). These solutions were assessed (using IMPM where applicable), and the results showed an overall reduction in cumulative neck loads (see Section 6.2.1.1 and Section 6.2.1.2).

Other analyses that were performed included individual differences, as well as comparing neck loads across individual tasks. A third analysis (not performed in the Canadian study) could be to examine injury mechanisms. That is, given that compression forces may lead to fractures, shear forces to herniated disks, and torques to muscle strain and stress, one might hypothesise that FEs have more soft tissue injuries while FP and NFP who would have more hard tissue fractures. Although injury mechanisms are not part of the Program of Work for this Research Task Group, IMPM could be used to develop injury mechanism hypotheses.

6.2.1.1 Task Sharing Assessment

The task sharing solution, first proposed by CH-146 aircrew subject matter experts, is based on the assumption that there are some tasks that are demanding and prolonged, which are largely borne by one operator member but could be shared among operators to limit over-use. For example, with a two-person helicopter pilot crew, the FP would have hands on cyclic and collective while the NFP would operate CDU and other console equipment often for the entire duration of a typical 1.5-hour night mission. The NFP has little relief from this flexed rotated head-down posture and their muscles will fatigue sometimes to a point where they can no longer support any neck-borne mass. The task sharing concept would allow the pilots to switch roles after some time period (e.g., every 30 minutes) so that neck muscles may rest and recover from the posture-induced fatigue.

A muscle fatigue model based on [10] was added to IMPM in order to compare the rates of muscle work and recovery associated with different task sharing time intervals. A 90-minute task sharing scenario was developed similar to the one described above. The IMPM results showed that for no task sharing, the NFP neck muscles would be totally fatigued (i.e., zero rested and activated muscles, thus muscles cannot support head and helmet system) after only 30 minutes or 67% of the mission, while the FP would never be totally fatigued [4]. Thus, the team total muscle fatigue would be 67%. However, if the NFP and FP were to switch roles every 45 minutes (half-way) then the NFP would only experience total muscle fatigue for 24% of the time, but the FP total fatigue would increase to 35%. Thus, the team total muscle fatigue would be 59%, which is still less than the 'no task sharing' condition. The model was run again for 15-, 9-, and 3-minute task sharing intervals, and the resultant team total muscle fatigue was 43%, 42%, and 48%, respectively, of the mission time. These results yielded an optimal task sharing interval of 9 minutes, which represents a 71% reduction in time that the NFP's muscles are totally fatigued, but it also represents a 22% increase of FP total muscle fatigue. Even if the task sharing interval was set more operationally, say, at every 30 minutes, there would still be a team total muscle fatigue about 50% of the mission time, which is still better than if there were no task sharing at 67%.

Clearly, task sharing through carefully designed in-flight work-rest scheduling can have significant benefits for reducing the loading (and therefore muscle fatigue) on an individual operator member and even reduce the total team loading for Griffon aircrew. On the other hand, aircrew would need to have the requisite training to enable effective task switching and in some tactical situations it may be better to leave a task with one operator member rather than risk losing mission awareness in the handover between operators. Nevertheless, it is a solution that has the potential to reduce neck loading and fatigue, and therefore mitigate neck pain.

6.2.1.2 Biomechanically Advantageous Postures

Motion capture data were collected from nine pilots (who performed both FP and NFP roles) and six FEs. This presented an opportunity to examine individual postures that produced more biomechanically advantageous postures that promoted lower neck loads.

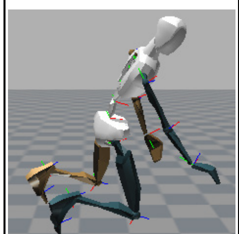
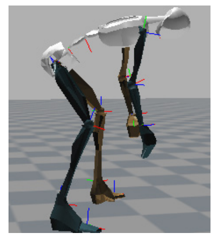
Table 6-1 summarises the results for FEs and for a subset of the more extreme postures. The table indicates the average group neck torque for the given posture along with the low and high torque generated by two individuals, respectively. It also shows a snapshot of the XSenS motion capture (i.e., zero rested and activated muscles, thus no muscles available to support head and helmet system) after only 30 minutes manikin for the individuals who produced low and high torque while performing the task.

For example, the low and high torque for individuals performing the 'Equipment Handling Inside' task is 6.3 Nm and 10.4 Nm, respectively. The high torque individual produces about 64% higher than the low torque individual since the standing position yields a much longer moment arm from the neck joint to the centre of mass of the helmet system. In general, it was observed that for all the postural sequences that involved moving around inside the cabin, the low task demands were those that limited the amount of time standing in a hunched posture. A standing posture could possibly be avoided by moving around inside the cabin on the knees, giving enough headroom to keep the torso in a more upright position. Other examples of biomechanically advantageous postures have been published [4].

Similar analyses were conducted for FP and NFP yielding 5% to 85% differences between highest torque compared to lowest torque [4]. During visual scanning tasks, experienced FPs who maintained the minimum required range of motion, used their eyes to scan part of the range, and performed their scan more slowly experienced lower resultant neck torques. Meanwhile, novice FPs would typically over-scan, move quickly and suddenly, and seek to use extreme postures to achieve maximum field of view experienced higher average resultant torques. When operating the centre console, maps, and documents, NFPs who adopted a more 'stooped' posture produced higher torques.

Thus, there is a range of postural strategies Griffon aircrew may adopt to perform their tasks but some strategies produce lower neck loads. IMPM may help to identify these biomechanically advantageous postures that may be formally (training) or informally socialised amongst aircrew. The basic finding of this analysis is to, whenever possible, maintain an upright position, rotate at the hips rather than the neck, and move slowly.

Table 6-1: Flight Engineering Lowest-Demand Task Techniques Summary [4].

Posture	Average Resultant Torque			Low Example	High Example	Summary
	Group Avg.	Low Avg.	High Avg.			
Equipment Handling Inside	8.5 Nm	6.3 Nm	10.4 Nm			High average is ~64% higher than low average. If the FE is on their knees while moving equipment, the amount of time that their torso will be horizontal is minimised and neck torque is minimised. If the FE is standing, their torso will be horizontal for the entire motion, and neck torque is maximized.

6.2.2 Rotary-Wing and Multi-Engine Aircraft Rear Aircrew Observational Task Analysis

The UK MOD Aircrew System research programme developed an approach to assess occupational tasks performed by rear aircrew to gather evidence to support the identification of postural risks for MSI in aircrew to identify and make recommendations concerning potential approaches to mitigate these risks [11].

The method adopted was based on established principles of task analysis and provided a method to assess key posture risks that may result in injury. Task analysis was based on observations and analysis of video recordings taken on board aircraft (C-130, Puma, and Chinook) during a variety of day sorties. It was observed that rear crew routinely move around, within and outside aircraft cabins both whilst aircraft are on the ground and in the air. These tasks involved interaction with significant load volumes and masses (internal and external) whilst operating in confined, moving spaces (aircraft). Figure 6-7 shows examples of typical severe postures that rear crew adopted during the sorties.

Tasks were identified, postures were characterised (i.e., moving, crouching, etc.), and the time spent in each posture was determined (Figure 6-8). Also, each task was defined as ‘good,’ ‘bad,’ or ‘severe’ by the SME. This characterisation was achieved using Observer XT (software package for the collection, analysis, and presentation of observational data). Figure 6-8 shows the output for tasks conducted in Chinook involving manipulation of under-slung loads.

As shown in Figure 6-8 for Chinook, both the Puma and C-130 had the most tasks with some ‘severe’ component, usually associated with observations through hatch/doors with the subject in a prone position.

This study identified the key postural risks and prioritised them. Most posture-related issues resulted when aircraft environments became so confined as to make it impossible to adopt a naturally comfortable posture irrespective of task. Practical mitigations to prevent poor postures in such conditions are limited. Confinement can be due to both the (limited) dimensions of a specific platform, or as a consequence of reducing crew-available space by the carriage of additional cargo within the cabin. However, improved design and provision of dedicated hand-holds/padding to areas of the cabin identified as being most associated with gripping, kneeling, stooping, and lying postures may be practical.

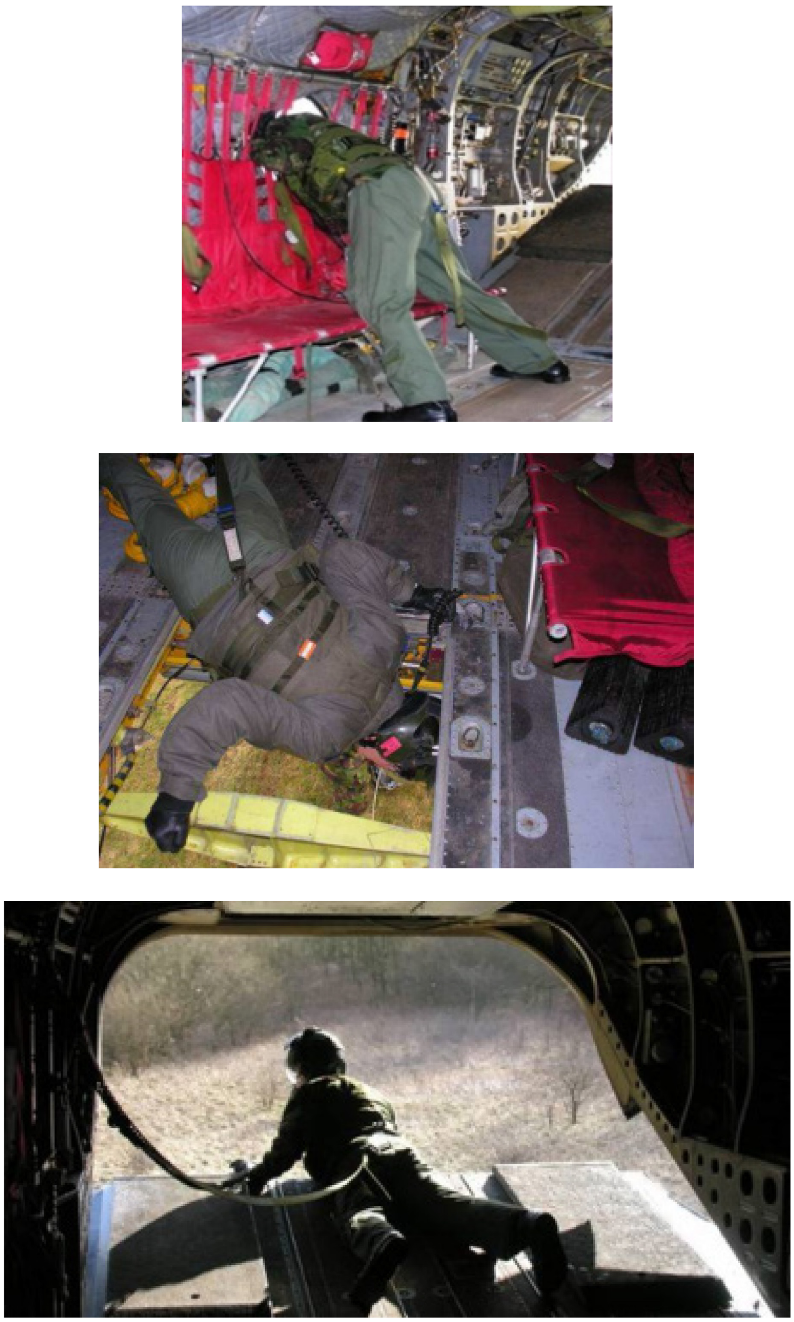
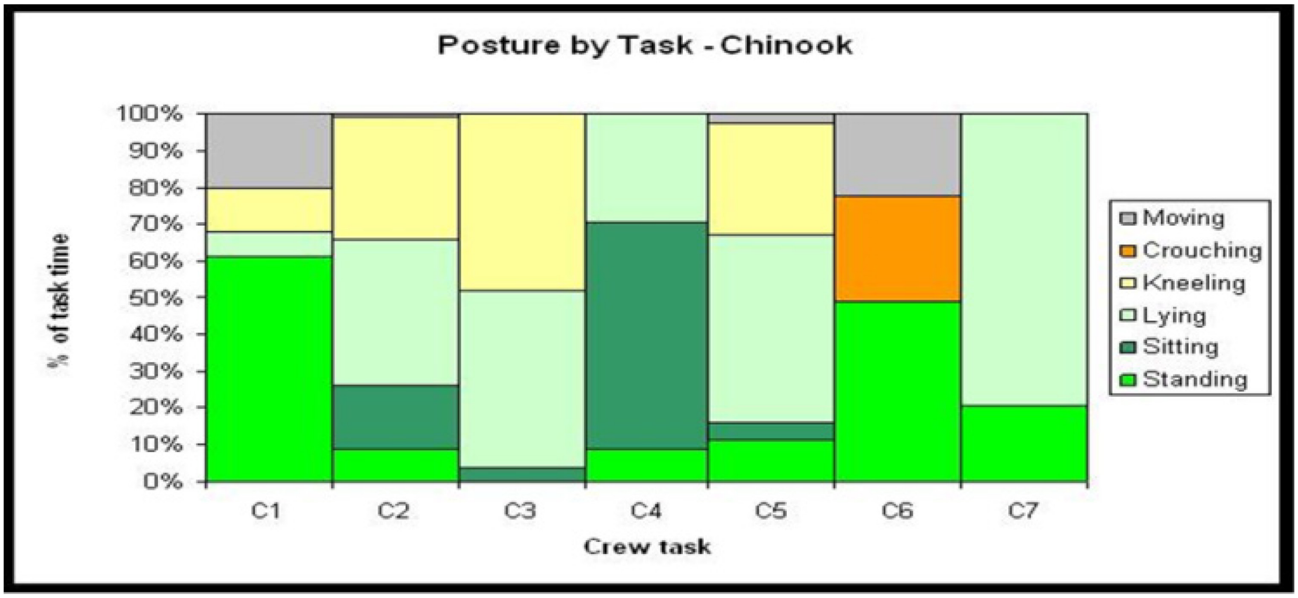


Figure 6-7: Typical Postures Adopted by Rear Crew. Photos reprinted with permission from QinetiQ. (Top: window check; Middle: centre hatch check; Bottom: hook movement and hatch observation.)



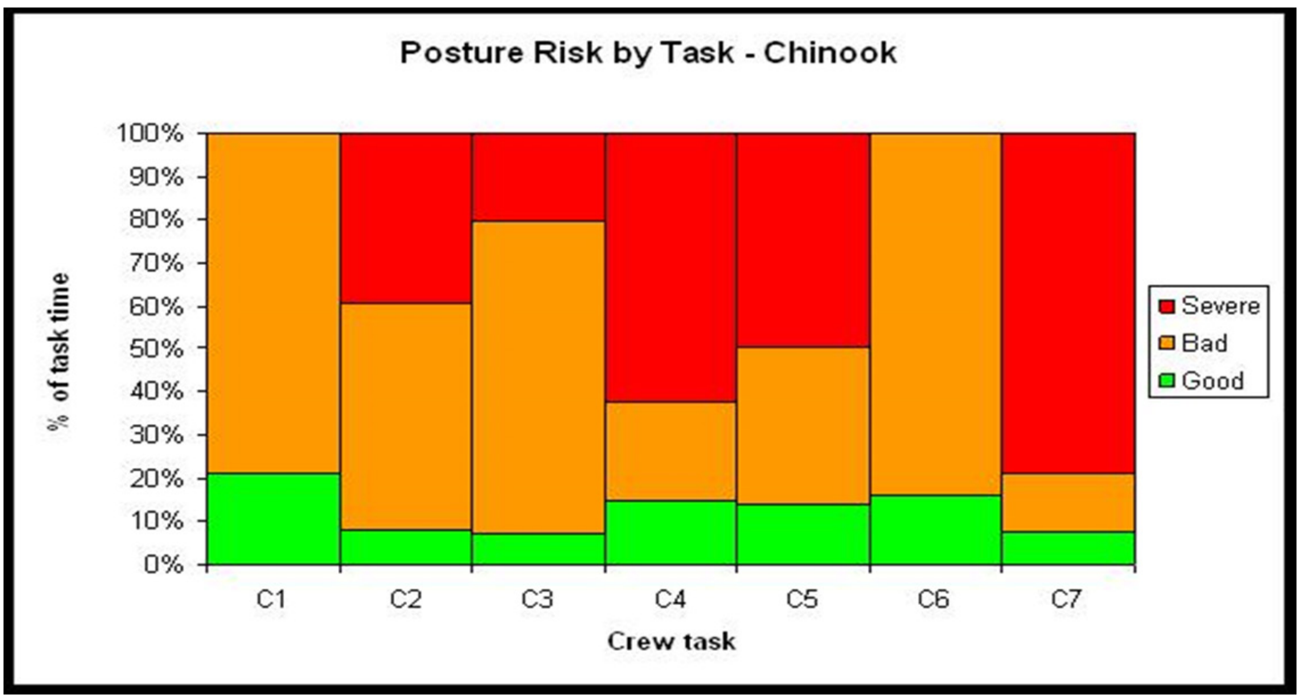


Figure 6-8: Characterisation of Posture by Task Against Time (Above) and Posture Risk by Task Against Time (Below).

The key 'severe' and 'bad' postures associated with rear crew tasks in Chinook, identified as having an ergonomic risk, were investigated using virtual modelling to demonstrate the benefit of posture changes on risk outcome [12]. This was done using commercial off-the-shelf digital human models (Jack and SIMM) to provide specific risk scores and estimates of selected parameters of human muscle that cannot be studied easily in the human. Motion capture techniques were used to drive the postures of the male digital human models of varying anthropometry (5th, 50th, and 95th percentile) (Figure 6-9). The outputs generated by the models were examined and used to identify how posture influenced risk, and where modifications to posture could be used to reduce risk associated with specific tasks.

Figure 6-9: Actual and Digital Human Model Posture Recorded Using Motion Capture Data. Photos reprinted with permission from QinetiQ.

The research found that none of the tasks examined generated neck and back forces that exceeded the National Institute for Occupational Safety and Health low back compression action limit of 3400 N. The highest calculated value was 78% of that level, associated with a task conducted in a kneeling posture at the centre hatch. Fifty percent of the tasks considered resulted in at least one score of ‘4,’ the highest (worst) ‘Ovako Working Postures Analysis’ rating [13]. All tasks analysed, except walking, produced scores of 3 for at least one of the anthropometric models. A score of 3 indicates the posture has harmful effects and that corrective action should be taken as soon as possible.

Muscle modelling revealed that tendon strain levels were not likely to be a concern in terms of acute injury; however, they were highest in the neck extensor muscles across all tasks. Based on the assessment, ways in which posture could be adjusted to reduce risk were examined. In two of the eight tasks, alterations in posture, achieved by reducing rotation of the pelvis and shoulders and the amount of flexion at the back, were identified. In two other tasks, whilst posture could not be modified, it is considered that the provision of additional external support to the torso would reduce scores somewhat. Whilst additional ergonomic handles and supports may yield slightly lower risk scores, additional analyses should be performed to see if the need of high-risk postures could be removed, or the frequency of high-risk postures could be reduced. However, it is accepted that the practical implementation of these changes to aircrew behaviours in a military environment may not be as straightforward as it would be in a more typical civilian working environment.

6.3 AIRCREW BEHAVIOUR SOLUTION RECOMMENDATIONS

This chapter examined possible neck pain prevention and management solutions pertaining to aircrew postures, postural sequences, and tasks. We noted that aircrew behaviours interact with the other four possible causal factors to further aggravate neck pain. On the other hand, aids to improve aircrew postures while performing tasks can be used to mitigate neck pain.

Two studies were conducted to identify areas for where aircrew behaviours increase the risk of neck pain, develop possible remedies, assess these solutions, and make recommendations to prevent and mitigate aircrew neck pain. These studies involved task analysis and numerical calculation of neck and back loads using biomechanical models. The models allowed us to assess a particular solution by comparing the model output before and after the intervention.

The assessed and recommended solutions from the Canadian study were:

- Training schedule modifications (see Section 4.4 on Work-Rest Cycles);
- Alteration in postures; and
- Task sharing.

The assessed and recommended solutions from the UK study were:

- Muscle strength training and recovery exercise protocols (see Chapter 4);
- Alterations in postures; and
- Task elimination / frequency reduction analysis.

Not surprisingly, two of six recommendations are linked to work-rest cycles and exercise, which have their own recommendations 4.5 and 4.2, respectively. 'Alterations in Postures' is a common recommendation whilst 'Task Sharing' and 'Task Elimination/Frequency Reduction' are unique solutions that flowed from the two independent studies.

Both studies emphasise the need to make these solutions applicable to the operational environment these solutions. That is, optimal solutions may not be operationally viable. And so we recommend that training for rear crew tasks consider including biomechanically advantageous positions and provisions for strategically located ergonomic handles and supports also be considered. Finally, we envision synergetic benefits when combining solutions from Chapter 3 (aircrew conditioning programmes) and Chapter 5 (optimal helmet system mass properties) with the solutions from this chapter.

Recommendation 6.1 (Section 6.2.1.1): Task sharing should be explored where tasks that are likely to contribute to neck pain can be shared: i.e., for aircraft with more than one crewmember.

Recommendation 6.2 (Section 6.2.1.2): Aircrew tasks that have been demonstrated as a likely contributor to increased risk of neck pain should be modified to include biomechanically advantageous postures.

Recommendation 6.3 (Section 6.2.2): Ergonomic handles and supports for rear crew should be used to promote biomechanically advantageous postures.

Recommendation 6.4 (Section 6.2.2): Aircrew tasks should be analysed to determine whether high-risk tasks can be redesigned, eliminated, or occur less frequently.

6.4 REFERENCES

[1] Bray-Miners, J., Osborne, A., and Tack, D.W. (2017). Modeling assessment of crewstation ergonomic solutions (p. 76). Toronto, Canada: Scientific Authority: Giovanni Fusina, Ph.D., DRDC-RDDC-2017-C140, Defence Research and Development Canada.

[2] Farrell, P.S.E., Tack, D.W., Nakaza, E.T., and Bray-Miners, J. (April 2016). Estimating aircrew neck load profiles using an integrated model of human physical work. Paper presented at the Aerospace Medical Association 87th Annual Scientific Meeting, Atlantic City, NJ.

[3] Farrell, P.S.E., Tack, D.W., Nakaza, E.T., Bray-Miners, J., and Farrell, C.M. (2014). Combined task and physical demands analyses towards a comprehensive human work model. Paper presented at the HFES 2014 Annual Meeting, Chicago, Il.

[4] Tack, D.W., Bray-Miners, J., Nakaza, E.T., and Osborne, A. (2016). Griffon 2 Project: Assessment of revised work distribution for Griffon helicopter operator (p. 71). Toronto, Canada: Scientific Authority: Philip S.E. Farrell, Ph.D., DRDC-RDDC-2016-C224, Defence Research and Development Canada.

[5] Tack, D.W., Bray-Miners, J., Nakaza, E.T., Osborne, A., and Mangan, B. (2014). Griffon Helicopter Neck Strain Project. Part 1: Mission function task analysis and physical demands analysis report. Part 2: Physical Demands analysis library. (p. 340). Toronto, Canada: Scientific Authority: Philip S.E. Farrell, Ph.D., DRDC-RDDC-2014-C228, Defence Research and Development Canada.

[6] Couture, C., and Richings, J. (1998). Physical demands analysis "the cornerstone of any return to work program." Retrieved from http://sibley.ca/wp-content/uploads/2011/04/Physical-Demands-Analysis-The-Cornerstone-of-an.pdf on 22 February, 2014.

[7] Myers, D.C., Gebhardt, D.L., Crump, C.E., and Fleishman, E.A. (1984). Validation of the Military Entrance Physical Strength Capacity Test (p. 188): Technical Report 610, U.S. Army Research Institute for the Behavioral and Social Sciences, Bethesda, MD.

[8] van der Molen, H.F., Sluiter, J.K., Hulshof, C.T., Vink, P., and Frings-Dresen, M.H. (2005). Effectiveness of measures and implementation strategies in reducing physical work demands due to manual handling at work. Scand J Work Environ Health, 31 Suppl 2, 75-87.

[9] Farrell, P.S.E., Maceda, E., Niri, A., Apostoli, C., McGuinness, C., Valikanthan, J., and Karokolis, T. (2018). Helmet systems comparisons using neck muscle activity and external load measurements: Helmet systems assessment trial. Toronto, Canada: DRDC-RDDC-2018-R163, Defence Research and Development Canada.

[10] Xia, T., and Law, L.A.F. (2008). A theoretical approach for modeling peripheral muscle fatigue and recovery. Journal of Biomechanics, 41, 3046-3052.

[11] Llewellyn, M.G.A., Longman, P., Marston, P., and Barker, N. (2010). Prevention of musculo-skeletal injury – Observational task analysis to reduce the risk of MSI in RW and ME aircrew. UK: QinetiQ.

[12] Llewellyn, M.G.A. (2013). Musculoskeletal risks in Chinook rear crew: Mitigations recommended from analysis using motion capture driven digital human models. QINETIQ/13/02815/2.0, Farnborough, UK.

[13] Karhu, O., Kansi, P., and Kuorinka, I. (1977). Correcting working postures in industry: A practical method for analysis. Appl Ergon, 8(4), 199-201.

Chapter 7 – NECK PAIN PREVENTION AND MANAGEMENT – AIRCRAFT WORKSPACE

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7.1 INTRODUCTION

The aircraft workspace can contribute to aircrew neck pain. Ergonomic factors that have been cited as potential causes of neck and back pain for helicopter pilots include sitting height clearance and instrument display design and location [1], while ergonomic issues for rear crew (gunners, crew chiefs, flight engineers, etc.) include crew seat design, particularly the backrest and leg spaces [2]. Additional workspace factors contributing to neck pain that are inherent in aircraft operations include vibration and G.

Aircraft Workspace is one of five possible causal factors of neck pain (Section 1.2) that involves not only workspace ergonomics but also austere environments – G, vibration, and altitude – within which aircrew must operate. These work conditions impact crew comfort and performance regardless of flying during the day or at night; although a night helmet system configuration seems to magnify the contribution of non-ergonomically designed workspaces and austere environments to neck pain.

MIL-STD-1472G provides design guidance for cockpit displays and controls to achieve the required operator performance, minimise skill and personnel training, achieve reliable personnel-equipment combinations, and foster systems design standardisation [3]. As a minimum these guidelines should be followed; however, they do not specifically address improving workspace designs in order to reduce the risk of musculoskeletal injury or pain.

In terms of austere environments, any additional centrifugal acceleration multiplies the external loads with each increase in G. Meanwhile, vibration adds a second order load component to the acceleration vector. Even flying at altitude may have an indirect impact on neck pain. That is, aircrew must wear oxygen mask systems, which add mass and inertia, and changes the centre of mass of the helmet system as discussed in Chapter 5.

This chapter highlights potential mitigating solutions by improving aircraft workspace ergonomics and reducing neck-level vibration. For full discussion of G and its effect on cumulative neck loading, see Section 4.2.2.2.1.3. Solutions for minimising G exposure are to: a) Determine the medical disposition of the pilot on a case-by-case basis (see Section 4.6); and b) Procedurally and/or mechanically limit the G level to a flight envelope in a non-deployed status in which the pilot remains asymptomatic until full function is restored.

7.2 COCKPIT AND CABIN ERGONOMICS

In addition to MIL-STD-1472G, the Society of Automotive Engineers (SAE) issues Aerospace Recommended Practice (ARP4754) for cockpit design, layout, installation and operation, which contain minimum requirements for the pilot's position in relation to the following aspects [4]:

- The ability to reach the controls without effort from a reference position (seatbelt attached, shoulder harness unlocked, pilot's eyes in reference position);
- Visibility of flight instruments without undue effort;
- Minimum visibility outside the cockpit; and
- Easy oral communication inside the cockpit.

However, even though aircrew may reach controls, see all instruments as well as Out-The-Window (OTW), and communicate, this recommended practice does not explicitly consider workspace design and layout in the context of maintaining a biomechanically advantageous posture. Since neck pain is such a prevalent problem, ergonomic design and evaluation procedures described above should also account for possible aircrew neck pain. Testing various ergonomic designs may incorporate modelling/simulation elements, as described in Chapter 3 and Chapter 6, in addition to ground and flight tests. This would help to identify compatibility issues, explore different "what if scenarios," and provide estimated neck loading reductions with new configurations.

The next stage of the evaluation would be a ground testing procedure with human participants. Here, motion capture measurements would be collected and used to estimate neck loading, and validate the Modelling and Simulation (M&S) results previously obtained (as in Chapter 6). Before flight testing, whatever redesign is made should be deemed airworthy by, for example, the Federal Aviation Administration or European Aviation Safety Agency for civil air traffic operations. Further, airworthiness of any new technology associated with neck pain solutions must be considered for military operations. Flight testing would be the final stage of this procedure, where operational issues would need to be validated and refined.

7.3 DISPLAYS

Aircraft flight displays deliver information to perform all flight and mission tasks such as taxi, take off, cruise, and land in all weather and day/night conditions. The primary modality of gathering this information is visual. Aircrew must have a clear and unobstructed view of the display panels regardless of any external factors that may cause the eyes to lose focus, such as sub-optimal helmet system mass properties, G forces, vibration, and poor ergonomic display design (information size, colour, shape, and location). Neck structures must work even harder to stabilise on a display if any one or all of these external factors are less than optimal, thus adding to the risk of neck injury and pain. Flight displays may be presented as a Head-Down Display (HDD), Head-Up Display (HUD), and Head- or Helmet-Mounted Display (HMD).

7.3.1 Head-Down Displays

HDDs are powerful and have excellent readability since they are connected directly to the avionics. Liquid Crystal Display light levels may vary from very low luminance levels during night operations to high levels in bright sunlight. Also viewing angles often approach 50°. One might argue that variable light levels and wider viewing angles make it easier to focus on the information and therefore the neck does not have to work as hard to maintain focus. It can be argued that the newer electronic 'glass' displays promote excessive attention focus or 'tunnel vision.' This, in turn, may contribute to neck stress and fatigue if the head must be in a flexed and slightly rotated position to view the displays.

For example, the Control Display Unit (CDU) is located on the centre console of the CH-146 aircraft. The Non-flying Pilot must look down and rotate their heads to operate the CDU sometimes for the entire mission. This position leads to the NFP having fatigued muscles for 67% of the time during a 1.5-hour mission (see Chapter 6). One solution is to introduce a reconfigurable Multi-Function Display that may be hand-held, placed on the knee, or perhaps mounted on the dashboard like the primary flight instruments or a HUD. Modelling and simulation yield 70% reduction in neck torque using a Multi-Function Display (MFD) in an optimal position that promotes a more head-up posture [5].

Similar to MFDs, Digital Knee Boards or Electronic Flight Bags (EFBs) display information such as maps, charts, check lists, and notes previously presented on paper. Thus, EFBs may afford some relief from neck loading compared to a centre console HDD.

7.3.2 Head-Up Displays

A HUD employs a transparent mirror or combiner located between the pilot's eyes and the front windscreen to reflect images generated in a projector unit and collimation lenses. The projector is typically located above the pilot's head for transport aircraft or behind the instrument panel of a fighter aircraft.

With an HDD, the aircrew member must shift gaze and focus between the external environment (located at infinity in optical terms) and the instrument panel (located within several centimetres). We postulate that this 'focus switching' may quickly fatigue muscles and result in missing an important event or disorientation. However, with a HUD, images are collimated or focused at infinity and projected onto a transparent mirror or combiner positioned between the aircrew's head and the windscreen. The images are superimposed on the external landscape allowing the pilot to simultaneously monitor the aircraft's environment and the data provided by on-board instruments (i.e., no 'focus switching'). Thus, as its name suggests, a HUD promotes a head-up position, which is a biomechanically advantageous posture.

7.3.3 Helmet-Mounted Displays (HMDs)

In general HMDs concern all head-supported optical displays including night vision goggles and sighting display. Night vision goggles are a special and provide only an improved night time picture to the crew. For this section, we are considering the more general aspects of HMDs where a display system can provide additional information display to the operator to enable improved operational capability.

Images or symbology displayed to the operator are focused at infinity and allow information to be displayed to the operator at all times and off bore-sight. Information can be co-located on the real world with the right system integration or simply provide flight information without the need to keep returning the HDD or HUD.

There are many different technologies used in HMDs. For instance, more modern systems are able to provide a colour symbology and imagery.

Care has to be taken when deciding on the information being displayed as operators will use this compelling information. While are operationally advantageous capabilities that can be provided with HMDs, these devices add to the head-borne mass properties (see Chapter 5) and may result in postures which are not biomechanically advantageous (see Chapter 6).

7.4 CONTROLS REDESIGN FOR ROTARY-WING AIRCRAFT

Pilots typically use a cyclic and a collective controller to move helicopter control surfaces. From an ergonomics perspective this results in the infamous "helo hunch." Pilots have to hunch over to use the controls and look out the window. Some studies have reported that a pilot's position using a cyclic and a collective controller leads to neck and back pain [6].

The NH-90 was the first military fly-by-wire helicopter, and the Bell 525 aircraft will be the first fly-by-wire commercial helicopter (Figure 7-1). As newer helicopters come into production with fly-by-wire systems, it will be easier to ensure that proper ergonomic considerations will go towards avoiding helo-hunch and mitigating neck and back pain. However, the question still remains whether improvements to legacy helicopter flight controls can be made to mitigate this problem. What would be the cost involved? What are the airworthiness and safety issues? Any controls redesign must go through an ergonomics evaluation procedure that includes modelling and simulation, ground, and flight testing.

Figure 7-1: Bell 525 Controls (http://www.bell525.com/setting-new-standard).

It is possible to redesign helicopter controls in a more ergonomic fashion. Indeed, if rotary-wing aircraft move towards digital flight control systems (i.e., "fly-by-wire"), it should be a simple matter to position the new controls in a way to minimise a hunched posture, and therefore mitigate possible neck and back pain. If digital control systems are not utilised, it should still be possible to configure the cockpit controls and seats in a more ergonomic manner. A "fly-by-wire" joystick control that has little control margin can be very difficult to use for a helicopter pilots to control the aircraft. Nevertheless, fly-by-wire technologies are being integrated into rotary-wing aircraft (fast jet and fixed-wing aircraft have had fly-by-wire technology for several decades).

7.5 ERGONOMIC SOLUTION ASSESSMENT

This section provides an example of how M&S can be used to assess some of the aircraft workspace solutions discussed above. As mentioned, M&S testing could be the initial test to determine whether a solution shows any differences in calculated/estimated neck loading. If it does, one might consider moving to human-in-the-loop ground testing.

The M&S platform used was IMPM (see Chapter 6 for full details). Note that for this particular study, neck joint angle data for a specific postural sequence (or task) were captured for only one participant who adopted both the FP and NFP roles, and one participant that performed FE tasks, and for both the current CH-146 Helicopter workspace layout, and then with the improved ergonomic solutions. However, only the start and endpoints of the motion capture files were imported into JACK, and the software then interpolated and calculated neck joint angles and neck loads between these time points. Thus, JACK represented consistent and repeatable movement strategies for each of the postural sequences. As a check, Visual 3D used the raw motion capture files; although the absolute values did not match, the values were in the same order of magnitude and the same data patterns emerged.

Since the M&S evaluation used anthropometric data for a single fifty percentile male, no statistically significant differences may be inferred from the following results. However, a future study is hoped to input actual anthropometric data that represents individual Griffon aircrew members [7], run up to 300 virtual aircrew, and then perform statistical analyses. Nevertheless, M&S provides a safe and cost-effective way for exploring potential solutions.

The following solution concepts, suggested by aircrew subject matter experts, were explored in this M&S study (the complete study details are found in Ref. [5]).

7.5.1 Radar Altimeter Monitor for Flight Engineers

The radar altimeter monitor concept was developed to mitigate the requirement of the FE to look at the Radar Altimeter (RADALT) at the front of the aircraft with awkward postures. The RADALT monitor concept includes a remote RADALT display (potentially on an MFD) that can be mounted in two different locations, on the frame of the side door and the back of the right front seat.

The results showed a decrease in resultant neck torque when the RADALT display was located on the door frame (3.5 Nm for day helmet configuration; 5.6 Nm for night helmet configuration) and on seat back (3.8 Nm day; 5.0 Nm night) compared to the current situation with no display (5.5 Nm day; 5.8 Nm night) and for 3 out of 4 slung load tasks. The one exception to this is occurred when the FE performed a Slung Load (Looking Back) task where the neutral posture at night resulted in an unusually low resultant torque (9.9 Nm day; 3.7 Nm night). It is possible that the FE intentionally adopted a more upright posture while completing tasks knowing that there was additional weight on their head. Meanwhile, when the RADALT display is introduced, the FE might not have been so conscious of the weight and adopted a less upright posture.

Note that the day condition resulted in the highest day resultant torque. The video of this run shows the participant hanging far out the door looking back at the Griffon tail in an exaggerated posture, without any regard for the day helmet configuration mass properties.

Generally speaking, a well-designed MFD has the potential to reduce neck torques during slung load tasks.

7.5.2 Better Seat Ergonomics

The better seat ergonomics concept applies to both the ‘rag-and-tube’ seat in the rear of the aircraft used by the FE, and the two front seats used by the FP and NFP. In both cases, seated posture was the main focus of the improved seat ergonomics. VIP seats with additional back support and seat cushion were used to compare the current ‘rag-and-tube’ seat given that the largest differences would be seen for FEs.

As expected during a Transited Seated posture, the VIP seat yielded less neck torque (3.2 Nm day; 4.0 Nm night) than the current seat (3.8 Nm day; 4.8 Nm night). However, the opposite is true for a scanning task where the FE must look back through the window (5.1 Nm day; 11.6 Nm night). This is due to the height of the VIP seat where the FE must adopt a hunched posture to look out the window. And so, the solution would be to lower the seat back height.

This example illustrates the power and necessity of M&S before generating physical mock-ups and ground testing. With a change to the VIP seat height, the VIP seat has the potential to reduce neck loads.

7.5.3 A Cyclic and Collective Redesign

The endpoints of postural sequences were manipulated in software such that the FP could place their hands on the cyclic and collective at a height that would allow the model's avatar to achieve a comfortable seated posture. The results show lower torque for the cyclic/collective redesign solutions (3.5 Nm day; 4.6 Nm night) only during the day condition compared to the current cyclic/collective design (4.1 Nm day; 4.6 Nm night).

One possible explanation for the same result at night is that there may not be much variance in neck posture when scanning OTW with NVGs, while during the day the FP has the opportunity to have a slightly head-down posture and yet achieve eyes forward, and perform the flying task. The new cyclic/collective position may afford a more erect posture and thereby reducing neck torques during a day mission.

7.5.4 Control Display Unit Redesign for Non-Flying Pilot

The CDU redesign option involved relocating the current CDU to a more forward and optimal location within the cockpit. The resultant torque for a left seat NFP (for example) and for the new CDU location (6.4 Nm day; 6.0 Nm night) was less than the current CDU location (8.1 Nm day; 9.8 Nm night). Although this solution yields the largest neck torque differences of all the solutions, the cost of relocating the CDU would likely be prohibitive.

7.5.5 Multi-Function Display Usage for Non-Flying Pilot

The MFD usage concept was developed to amalgamate several of the NFP tasks, including physical maps and documentation as well as MX-15 operations, into one display unit that could be positioned in several possible locations in the cockpit: forward mounted, thigh mounted, handheld, and an optimal location determined by SME. The optimal (4.4 Nm day; 4.6 Nm night) and handheld locations yield similar low neck torques followed by thigh mounted, forward mounted, and then current documentation and MX-15 (9.3 Nm day; 10.9 Nm night) usage. However, integrating MFDs into current helicopter operations will require significant discussions, redesign, test and evaluations with air forces' programme offices and industry.

7.5.6 Combined Ergonomic Solutions for Cumulative Mission Analysis

The previous analyses generated neck torque results for individual tasks (postural sequences) but not for the mission as a whole. For this analysis, FP cyclic/collective redesign, NFP MFD and CDU redesign, and FE VIP seat and RADALT display were incorporated into the model and the simulation was run for a full Logistics mission (Vignette 1) and Training mission (Vignette 2).

Figure 7-2 shows the cumulative resultant torque over the course of a Logistics mission, for the three roles, and day/night helmet system configurations. In all day time conditions for Vignette 1, the combined ergonomic solutions resulted in a decrease of cumulative resultant torque of 18.6% for FP, 17.3% for NFP, and 20.8% for FE. In all night time conditions for Vignette 1, the combined ergonomic solutions resulted in a decrease of cumulative resultant torque of 16.7% for NFP and 17.0% for FE, but an increase in torque of 2% for FP. Note that the Transit Seated reference line denotes the cumulative torque if the only task for the duration of the mission was a Transit Seated task. Also, note that compression and shear forces were collected but not provided herein.

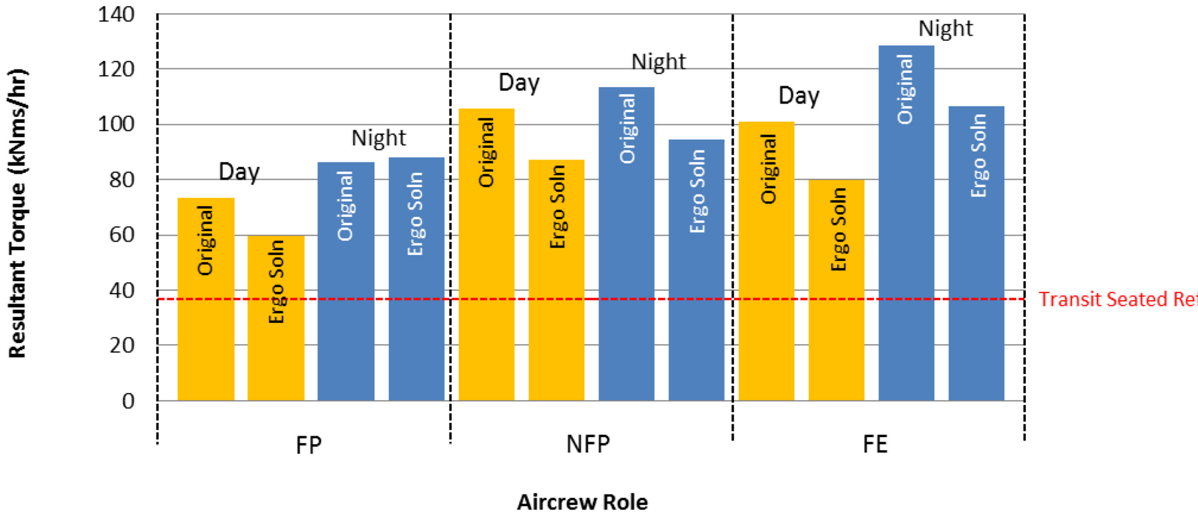

Figure 7-2: Mission Vignette 1: Original and Ergonomic Solution – Resultant Torque by Aircrew Role.

Figure 7-3 shows the cumulative resultant torque over the course of a Training mission and for the three roles and day/night helmet system configurations. In all day time conditions for Vignette 2, the combined ergonomic solutions resulted in a decrease of cumulative resultant torque of 17.2% for FP, 17.3% for NFP, and 3.3% for FE. In all night time conditions for Vignette 2, the combined ergonomic solutions resulted in a decrease of cumulative resultant torque of 3.8% for NFP and 15.2% for FE, but an increase in torque of 2% for FP. The percentages for both missions were similar for FP, but significantly less for NFP and less for FE during the Training mission. Thus, it is prudent to determine how a proposed solution impacts not only individual tasks, but also complete and different missions. IMPM allows one to explore these analyses.

In summary, aircraft workspace factors that negatively impact neck pain include non-ergonomic control and display design. However, HUDs and side arm controllers may promote a more neutral posture. A number of ergonomic solutions were explored in a modelling and simulation environment, and differences between the ergonomic solutions and current workspace configurations were noted; however, changing aircraft workspaces to accommodate solutions may be cost prohibitive. Potential next steps are for platform managers or the programme office to determine which solutions would move forward into ground testing.

7.6 HELICOPTER SEAT VIBRATION MITIGATION

Vibration transmitted from the blades through the fuselage to the human body can create a wide range of short-term (e.g., discomfort, fatigue) and long-term (e.g., chronic pain, spinal misalignment) health issues. Studies have shown that amplitudes of vibration within 4 to 6 Hz range are amplified at the head [8], [9], [10], making it imperative for the health and safety of aircrew that head vibration be accounted for in the exposure standards. Using the ISO-2631-1:1997 to evaluate the vibration levels on a Bell-412 (civilian Griffon) helicopter, vibration exposure levels were, in general, unacceptable for the aircrew [10], [11]. For instance, head vibration was significantly greater than seat vibration under three different levels of vibration and even with the use of a vibration mitigating cushion [10]. Although head vibration ISO weightings do not exist [8], [10], [12], [13], if head vibration data were applied to the weightings which do exist for the seat, health weighted head vibration has been shown to be significantly increased with comfort weighted acceleration moving into the next category (e.g., from “Fairly Uncomfortable” to “Uncomfortable” [10]). Furthermore, helicopter vibration changes through track-and-balance tuning process of the main rotor, which increased the helicopter vibration by 0.006 G resulted in an increased vibration of the pilot’s head by 0.01 G [8]. While such levels were considered safe according to the ISO-2631-1:1997 weightings, head and neck movement were not taken into account, thus emphasising that any effort to reduce the aircraft vibration would be beneficial for the health and safety of aircrew.

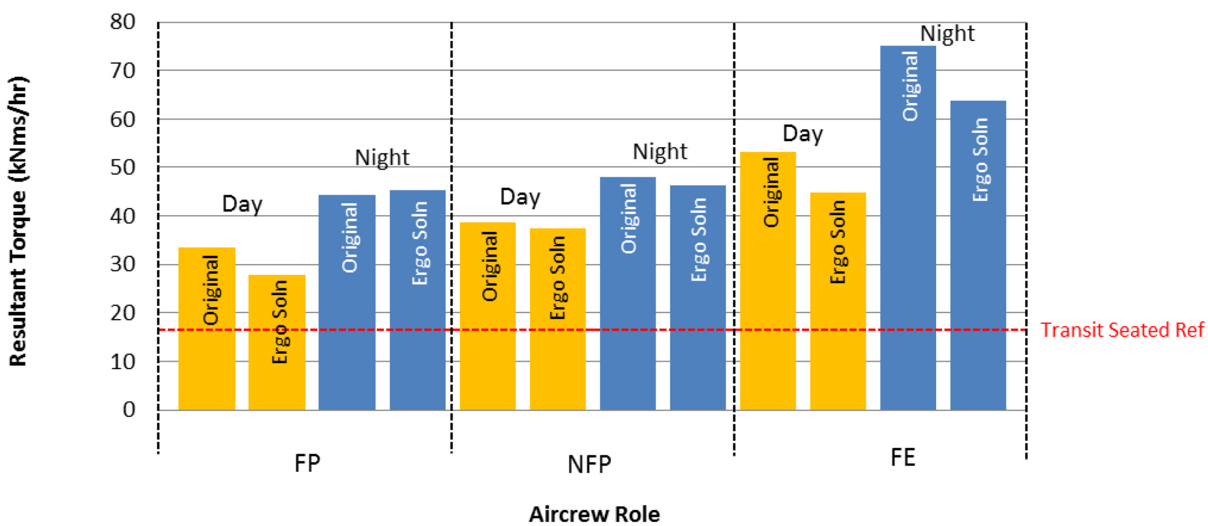

Figure 7-3: Mission Vignette 2: Original and Ergonomic Solution – Resultant Torque by Aircrew Role.

In attempts to reduce whole-body vibration exposure in various flight conditions, vibration mitigation methods have attracted significant attention in the research community, ranging from passive and active blade control to the manipulation of local structures. The vibration control of local structures, such as the blade, trim panels, seat structures, and seat cushions, offers relatively more promising solutions to the complex problem of whole-body vibration. This is primarily due to the fact that these systems have fewer certification requirements, offer easier implementation, and have lower weight penalties [11]. In order to suppress the vibration of these local structures, the use of dynamic vibration absorbers is considered to be a viable solution which can be implemented using a passive, semi-active, or active control approach, depending on the dynamic characteristics of the system.

7.6.1 Passive Control

Although passive systems are simple, low cost methods of vibration isolation, the simplicity inherently leads to a non-adaptive system since the system parameters are fixed. In general, passive control methods work well for mitigating high frequencies or a narrow frequency range, but tend to be poor at low frequencies [14]. This is evident when considering the dynamics of a single degree-of-freedom system, where the transmissibility of such a system is the ratio between the output and input of the system. In passive control, the dynamic parameters of the system can be set to achieve a desired damping ratio and damped natural frequency. Since the parameters are fixed at design, careful selection of the materials and designs must be considered and tested prior to implementation.

While various vibration mitigation solutions have been investigated, anecdotal reports indicate that many aviation workers use their own preference of cushions regardless of airworthiness and other safety considerations. Recent studies have examined two novel energy absorbing materials aimed at re-designing the Bell-412 (Griffon) helicopter seat cushions [11]. These materials were selected based on a literature review that identified materials used in low frequency vibration reduction applications. The Hybrid Air Cushioning System (HACS) uses a structural design that absorbs energy by bleeding air though channelled passages in the structure [15], [16]. These vents are interconnected and cause the airflow to choke when air is forced through them. This choked flow dissipates much of the energy in the lateral direction, instead of being transmitted through the thickness of the cushion. Sorbothane is a highly damped, viscoelastic thermoset polyurethane material developed for use in shock and vibration applications. This material dampens vibration by transferring mechanical energy into thermal energy, which is then removed from the system by heat transfer. Flight test results indicated that the most effective combination was the urethane-based HACS combined with the original seat cushion. This combination was able to reduce the vibration at the pilot and co-pilot's heads in all but one flight (2 G turn) condition [16], [17]. This solution is currently being implemented in National Research Council Canada's (NRC's) helicopters as it is a low-cost solution, and provides improvement in 1/rev and 4/rev vibration suppression.

Manikin and human testing have provided evidence of the effectiveness of vibration mitigating cushions in reducing the vibration exposure to the occupant [10], [17], [18]. As a measure of neck strain, neck EMG amplitude, force, and median frequency were each influenced by cushion type, whereby neck strain was increased with the Original Equipment Manufacturer cushion compared to the mitigating cushion. Furthermore, the mitigating cushion was effective in significantly reducing both seat and head acceleration under three different vibration levels [10], [18]. This study also demonstrated that a vibration mitigating cushion reduced seat acceleration by 12.7% (8% at the head) and extended the minimum risk exposure duration by 36 minutes according to the ISO-2631-1:1997 exposure standards, providing stakeholders with an option to extend missions and reduce health risks [18].

7.6.2 Semi-Active Control

Semi-active vibration control offers an intermediate method between passive and active control. Unlike passive systems, semi-active devices are adaptive and have dynamic properties that can be controlled. Materials used for semi-active control are primarily electrorheological and magnetorheological fluids which respond to changes in electric and magnetic fields, respectively.

Magnetorheological fluid dampers have been investigated for mitigation effectiveness [19], [20] and on existing SH-60 Seahawk crew seats [21], [22]. In these studies, the dampers could be controlled in real time, thereby altering the damping force of the system to suppress vibrations [21], [22]. They were placed in series with the fixed load energy absorbers to maintain crash-worthiness requirements. For the real-time control of the dampers, the system was treated as a single degree-of-freedom system, and a skyhook algorithm was implemented to reduce the absolute velocity of the controlled mass [23]. For a 50th percentile male pilot, the semi-active control approach was able to reduce the 4/rev vibration, the dominant N/rev for the SH-60, by 76%. The isolation values were similar for different pilots, as well as for a higher amplitude input. Despite the effective cancellation of the 4/rev, the system amplified the 1/rev for all conditions tested.

7.6.3 Active Control

Active control offers the highest degree of adaptability in vibration reduction. The resulting system can be costly, complex, and power intensive; however, the high degree of controllability offers the greatest performance and health potential. Active vibration control systems use actuation devices that provide forces to counteract the vibratory forces. Ideally, this applied force would be of equal magnitude and opposite phase as the vibrations, implying that the net force at the point of isolation is zero, and therefore no vibration is transmitted further through the structure to the occupant.

In 1986, a group from Canadian Aviation Electronics presented perhaps the earliest attempt at developing an active vibration control seat for helicopter aircrew [24]. The concept applied was to repurpose a G-Seat, normally used in flight simulation, to actively dampen vibrations for the helicopter pilot. A G-Seat simulates forces experienced during flight by applying pressure via cells filled with air to various locations on the human body. The air pressure in these cells can be controlled by pneumatic or hydraulic actuation [25]. Active seat technologies are currently being investigated by the National Research Council Canada (NRC) and United States Naval Air Systems Command (NAVAIR).

7.6.3.1 Modal Shaker Active Seat

A proof of concept approach has been investigated by the NRC to overcome the limitations of semi-active control for eliminating the helicopter N/rev rotor harmonics [26]. Helicopter flight vibration data was used to determine the necessary stroke and force requirements of the actuator, and the LING LMT-100 modal shaker was selected to control vertical vibrations. Although the shaker is bulky in size, the controller was developed using the Filtered-x Least Mean Square algorithm with on-line system identification techniques and was equipped with feedback control for the suppression of resonant peaks in the system. Testing was conducted on a Bell-412 seat with a manikin placed atop as the occupant, and the manikin's helmet chosen as the target of location for vibration reduction.

A combined vibration profile was created which contained a random spectrum ranging from 5 – 50 Hz and 4 simultaneous N/rev harmonic tones (1, 2, 4, and 8/rev peaks), with an overall input vibration level of 0.22 g-rms. The active control system effectively reduced the vibration level of the harmonic peaks by 35% at the 2/rev and 32% at the 4/rev; however, the 1/rev harmonic peak was not reduced likely due to insufficient force generation at the low frequency [27]. Thus, it is possible to reduce the helicopter vibration at the seat location by means of active control.

7.6.3.2 Piezoelectric Actuator Active Seat

The use of piezoelectric stack actuators for active control has also been investigated [16], [28]. Two parallel piezoelectric actuators, fitted to a Bell-412 helicopter seat, were tested using a manikin on a seat that was excited using a modal shaker. The placement and angle of these actuators was selected so that the passive system dynamics were improved, and to allow control of vertical and fore/aft directions simultaneously. A combined vibration profile was created consisting of a random spectrum between 4 – 50 Hz combined with the N/rev harmonics for an overall vibration level of 0.05 g-rms. The controller suppressed the N/rev harmonics by 69% at the 2/rev and 50% at the 4/rev in the fore/aft direction, in addition to the suppression of resonant peaks excited by the random profile [16], [28]. No appreciable reduction was observed in the 1/rev peak due to the stroke limitation of the piezoelectric actuators.

7.6.3.3 Multi-Axis Active Control Helicopter Seat System

A novel multi-axis active control system for helicopter seats is currently under development and investigation at the NRC. This system is comprised of two box-shape mounts where each mount is installed under one seat leg and houses six actuators where each pair of actuators is acting in one direction (X, Y, Z directions) [30], [31]. Operation of the mechanical system is controlled by a Multi-Input Multi-Output Filtered-X Least Mean Square algorithm implemented in Simulink. Using three categories of manikins, the system was evaluated under a combined vibration profile. This profile consisted of N/rev harmonics with an overall vibration level of 0.05 g-rms superimposed on a random spectrum between 4 – 50 Hz. Initial assessments of the results reveals significant reduction (> 90% reduction) in all N/rev harmonics [29], [30]; the system is under undergoing extensive evaluation.

A Magnetorheological (MR) seat suspension system was retrofitted to the MH-60R Seahawk crew seat to provide semi-active control of harmful cockpit vibrations in a joint effort by NAVAIR and the University of Maryland [32]. Energy absorbing devices within current seating systems will not stroke until a tuned load threshold is reached, which acts as a stiff link between the seat and the floor during normal rotorcraft vibration. Because of this, these systems do not isolate the pilots from cockpit vibration. In this effort, an MR suspension was implemented in series with the existing energy absorbing devices. Experimental vibration testing results have shown that this system reduces the dominant rotor-induced vertical vibration at the blade passage frequency transmitted to the occupant by over 90%, which is an 86% improvement over the original MH-60R crew seat. Dynamic crash testing performed on the NAVAIR horizontal accelerator indicated that the MR retrofit did not impair the seat's crash safety. This test indicated that the MR suspension reduces peak lumbar loading from 1,950 lb to 1,250 lb when compared to the original MH-60R crew seat. In a 2013 flight test in a MH-60R, the pilot described vibration-induced movement of his hand with respect to his instrument panel. While in the MR-retrofit seat, he noticed lateral relative motion of his hand, but not vertical (the direction that the system was designed to attenuate), which differs from the standard seat in which the relative motion of the hand is strong in all directions. This suggests that the MR system provided significant attenuation of vertical vibration which may reduce pilot fatigue and could improve pilot control and visualization of the instrument panel.

7.6.4 Summary of Strategies to Reduce Vibration

Although the presented solutions have made considerable improvements to whole-body vibration exposure, further research in this area is ongoing. Each of the three control approaches has benefits and limitations which justify their use in certain circumstances. Ongoing research efforts include a semi-active controllable cushion layer and the next iterations of active seat systems. Vibration mitigation lengthens the time before reaching the caution zone of the ISO-3631-1:1997 for health risks and provides evidence for expected long-term health benefits.

It is recommended that vibration exposure be considered during the seat procurement process and where possible to utilise vibration mitigating materials in the seat to reduce aircrew spinal health deterioration.

7.7 RECOMMENDATIONS

We recognise that any modification to the aircraft workspace will come with significant costs both in terms of mechanical, hardware, and software changes as well as the costs associated with airworthiness recertification. Other costs may include additional training with the new equipment. Nevertheless, the Aircraft Workspace recommendations may be considered during a major mid-life upgrade of the air platform or procurement of a new aircraft capability.

Recommendation 7.1 (Sections 7.4 and 7.5): In order to reduce neck load exposure, future workspace design should consider the potential for repositioning certain aircraft displays and controls to achieve more biomechanically advantageous postures.

Recommendation 7.2 (Section 7.6): For helicopters, track-and-balance maintenance and tuning should be performed regularly to reduce vibration at head level, thus minimising neck loading and muscle activity.

Recommendation 7.3 (Sections 7.6.1 and 4.2.2.5): For helicopters, crashworthy vibration mitigation cushions should be implemented to reduce vibration at head level, thus minimise neck loading and muscle activity.

Recommendation 7.4 (Sections 7.1 and 4.2.2.2.1.3): For fast jets, the medical disposition of the pilot should be determined on a case-by-case basis with mechanically and/or procedurally limiting high-G manoeuvres in non-deployed roles to a level in which the pilot remains asymptomatic until full function is restored, whenever operationally feasible, in order to prevent recurrent injury and ultimately reduce cumulative neck loading.

7.8 REFERENCES

[1] Chafé, G.S., and Farrell, P.S.E. (2016). Royal Canadian Air Force CH-146 Griffon aircrew 2014 spinal musculoskeletal trouble survey. Toronto, Canada: Scientific Report, DRDC-RDDC-2016-R179, Defence Research and Development Canada, Toronto, Canada.

[2] Grant, K.A. (2002). Ergonomic assessment of a helicopter crew seat: The HH-60G flight engineer position. Aviat Space Environ Med, 73(9), 913-918.

[3] USAAMC. (2012). United States Army Aeromedical Center (USAAMC): MIL-STD-1472G Department of Defense design criteria standard: Human engineering (Vol. MIL-STD-1472G, 11 January 2012). Redstone Arsenal, AL: United States Government.

[4] SAE. (2010). Guidelines for Development of Civil Aircraft and Systems, ARP4754A: Society of Automotive Engineers. Warrendale, PA.

[5] Bray-Miners, J., Osborne, A., and Tack, D.W. (2017). Modeling assessment of crewstation ergonomic solutions, p. 76. Toronto, Canada: Scientific Authority: Giovanni Fusina, Ph.D., DRDC-RDDC-2017-C140, Defence Research and Development Canada.

[6] Hadjipavlou, A.G., Tzermiadianos, M.N., Bogduk, N., and Zindrick, M.R. (2008). The pathophysiology of disc degeneration: A critical review. J Bone Joint Surg Br, 90(10), 1261-1270. doi: 10.1302/0301-620X.90B10.20910.

[7] Keefe, A.A., Angel, H., and Mangan, B. (2015). 2012 Canadian Forces Anthropometric Survey – Final Report: DRDC-RDDC-2015-R186, Defence Research and Development Canada, Toronto, Canada.

[8] Craig, G., Wright Beatty, H.E., Alexander, M., Wickramasinghe, V., and Keillor, J. (2016). Pilot head and whole-body vibration response to tuning the track-and-balance of a Bell 412 main rotor. Ottawa, Canada: FTR-FRL-2015-0072, National Research Council Canada, Aerospace, Flight Research Laboratory.

[9] Paddan, G.S., and Griffin, M.J. (1988). The transmission of translational seat vibration to the head – I. Vertical seat vibration. J Biomech, 21(3), 191-197.

[10] Wright Beatty, H.E., Law, A., Thomas, J.R., and Wickramasinghe, V. (2018). Amplified pilot head acceleration and neck muscle strain: Effective vibration mitigation. Aerospace Medicine and Human Performance, 89(6), 1-10.

[11] Wickramasinghe, V. (2012). Dynamics control approaches to improve vibratory environment of the helicopter aircrew. (Ph.D.), Carleton University, Ottawa, Canada.

[12] Madison, A.M., Weisenbach, C.A., Shivers, B.L., Rooks, T.F., Fralish, V.R., Dorman, D., . . . Chancey, V.C. (2016). Evaluation of military tactical ground vehicle dynamic exposure ride signatures via risk assessment classification. Paper presented at the SAFE 53rd Annual Symposium, Orlando, FL.

[13] Smith, S.D. (2002). Characterizing the effects of airborne vibration on human body vibration response. Aviat Space Environ Med, 73(1), 36-45.

[14] Crocker, M.J. (2007). Handbook of Noise and Vibration Control. Hoboken, NJ: John Wiley.

[15] Colvin, D.P., and Colvin, C.S. (1991). Cushioning Structure, Raven Marketing Inc, Appl. #EP19920915469, EP0595887A1 United States Patent No.

[16] Colvin, D.P., and Colvin, C.S. (1996). Cushioning Structure, Appl. #08/178,265, 5518802 United States Patent No.

[17] Chen, Y., Wickramasinghe, V., and Zimcik, D.G. (2011b). Investigation of helicopter seat structural dynamics for aircrew vibration mitigation. Journal of the American Helicopter Society, 56(1).

[18] Chen, Y., Senarath Yapa, U., Price, A., and Wickramasinghe, V. (2017). Evaluation of aircrew whole-body vibration and mitigation solutions for helicopter flight engineers. Paper presented at the American Helicopter Society International 73rd Annual Forum and Technology Display, Texas, USA.

[19] Wright Beatty, H., Law, A., Thomas, R., Yapa, U.S., Prigli, A., Ensan, M.N., and Wickramasinghe, V. (2016). Effects of vibration level and a vibration mitigating cushion on neck strain using a human rated shaker facility, Report No. LTR-FRL-2016-0069, p. 66: LTR-FRL-2016-0069, National Research Council Canada, Ottawa, Canada.

[20] Choi, Y.-T., Wereley, N.M., and Jeon, Y.-S. (2005). Semi-active vibration isolation using magnetorheological isolators. Journal of Aircraft, 42(5), 1244-1251.

[21] Wereley, N.M., and Pang, L. (1998). Nondimensional analysis of semi-active electrorheological and magnetorheological dampers using approximate parallel plate models. Smart Materials and Structures, 7, 732-743.

[22] Hiemenz, G.J. (2007). Semi-active magnetorheological seat suspension for enhanced crashworthiness and vibration isolation of rotorcraft seats. (Ph.D.), Maryland, USA.

[23] Hiemenz, G.J., Hu, W., and Wereley, N.M. (2008). Semi-active magnetorheological helicopter crew seat suspension for vibration isolation. Journal of Aircraft, 45(3), 945-953.

[24] Karnopp, D., Crosby, M.J., and Harwood, R.A. (1974). Vibration control using semi-active force generators. Journal of Engineering for Industry, 96(2), 619-626.

[25] Landolt, J. (1985). Backache and back discomfort. AGARD Conference Proceedings No. 378, AGARD-CP-378, NATO Research Technical Organisation, Paris.

[26] McKinnon, G.M. (1985). Canada Patent No. Helicopter Seat Isolation System, CAE Electronics Ltd., Appl. #06/802739, 4634083, Canada.

[27] Chen, Y., Wickramasinghe, V., and Zimcik, D.G. (2015). Development and evaluation of hybrid seat cushions for helicopter aircrew vibration mitigation. Journal of Intelligent Material Systems and Structures, 24(13), 1633-1645.

[28] Chen, Y., Wickramasinghe, V., and Zimcik, D.G. (2009). Development of adaptive seat mounts for helicopter aircrew body vibration reduction. Journal of Vibration and Control, 15(12), 1809-1825.

[29] Chen, Y., Wickramasinghe, V., and Zimcik, D.G. (2011a). Development of adaptive helicopter seat for aircrew vibration reduction. Journal of Intelligent Material Systems and Structures, 22(5), 489-502.

[30] Graham, S., Fereidooni, A., Chen, Y., and Wickramasinghe, V. (2017). Investigation of a parallel active vibration isolation mount for mitigation N/rev helicopter vibrations. Paper presented at the AIAA SciTech Forum, Grapevine, Texas, USA.

[31] Hadj-Moussa, F., Fereidooni, A., and Chen, Y. (2018). Development of a multi-axis active seat mount to mitigate vibration transmission to helicopter aircrew. Paper presented at the AIAA SciTech Forum, Kissimmee, FL.

[32] Sztein, P., Hiemenz, G.J., Hu, W., Wereley, N.M., and Glass, W. (2013). Results of the first navy test flight of a semi-active magnetorheological helicopter crew seat suspension for vibration isolation. Paper presented at the AHS International, Phoenix, AZ.

Chapter 8 – INTEGRATING SOLUTIONS INTO OPERATIONS

8.1 ADMINISTRATIVE AND ENGINEERING SOLUTIONS

The RTG has proposed and assessed several administrative and engineering solutions via literature reviews, modelling and simulation, experimentation, and subject matter expert opinion. No single solution will mitigate chronic aircrew neck pain. Rather, the hope is that a combination of several solutions can be integrated synergistically resulting in a significant reduction of neck pain prevalence rates. Also, solutions should be implemented to prevent neck pain from the beginning of a military aircrew member's career since chronic neck pain is a cumulative effect of higher-than-normal neck load exposures over one's career [1].

Sometimes integrating an individual solution into operations without considering the complete system may yield unintended consequences. For example, the introduction of a fragmentation vest with heavy metal plates for pilots may increase survivability; however, the fragmentation vest will further degrade the pilot's posture, restrict motion, interfere with the helmet, and cause further neck and back pain. Thus, a systems approach is needed when integrating solutions into operations.

As a reminder, administrative or procedural solutions include:

- The Professional Athlete Model:
  - Exercise;
  - Education;
  - Physiotherapy; and
  - Nutrition.
- Smart Scheduling (Work-Rest Cycles).
- Limiting G (procedurally).
- Task Sharing (multi-crew only).
- Redesigning tasks to promote biomechanically advantageous postures.

Engineering solutions include:

- Lighter, more balanced, lower inertia helmet system;
- Ergonomic repositioning of controls, displays, and seats to produce biomechanically advantageous postures;
- Additional hand-holds and braces to assist with extreme postures;
- Vibration mitigation seat technologies;
- Track-and-balance tuning and maintenance of helicopter rotors; and
- Limiting G (mechanically).

Several questions remain with respect to integrating solutions into aircraft operations. Can the solutions be implemented in an existing platform or should they be considered only when designing new platforms? Are they easily implementable? What are the cost/benefit trade-offs? This chapter raises some questions and issues to be considered when integrating solutions into operations and suggests a number of ideas for consideration.

8.2 COST OF NECK PAIN AND SOLUTIONS

8.2.1 Cost Considerations of Operationally Relevant Neck Pain

To this point the impact of neck pain on performance has been considered but it must not be forgotten that there are financial costs associated with aircrew neck pain. Apart from performance degradations which are difficult to quantify, neck pain can lead to reduced hours flown. Not all countries have data on this, but some examples are shown here:

- A survey of Australian fast jet aircrew showed 93% of respondents had experienced neck pain in the past twelve months that led to them performing their flight-related tasks sub-optimally, and additionally 68% of respondents self-grounded due to neck pain for periods of greater than three days through that time [2]. This equated to seven man-years of time lost per annum. There is an inherent cost to this lost time as to maintain the force elements at readiness the operator community needs to be scaled to accommodate this.
- Partial data from the Belgian Air Force show that from 2014 to 2017, 42 days of grounding were officially registered in the military medical database for fifteen pilots. This number is likely to be the 'tip of the iceberg' and out of fear of consequences on their flying career, many more pilots are likely to have taken advice from civilian doctors who would not be registered in the military database. This is a significant amount of lost flying time for a small air force.
- Some operators are either lost to the service or are re-streamed to other platforms/roles. The result of this is that the high investment in their training is lost. The Finnish Air Force has data going back as far as 1995 (see Section 4.4.1). Fast Jet pilots were followed from the time they started their jet training. From these data, a linear survival curve shown in Figure 8-1 indicates that degenerative changes developing in spine occur slowly and take place across different phases in the training syllabus. From 1995 to 2015, 16% were given waivers with Gz limitations due to neck pain.

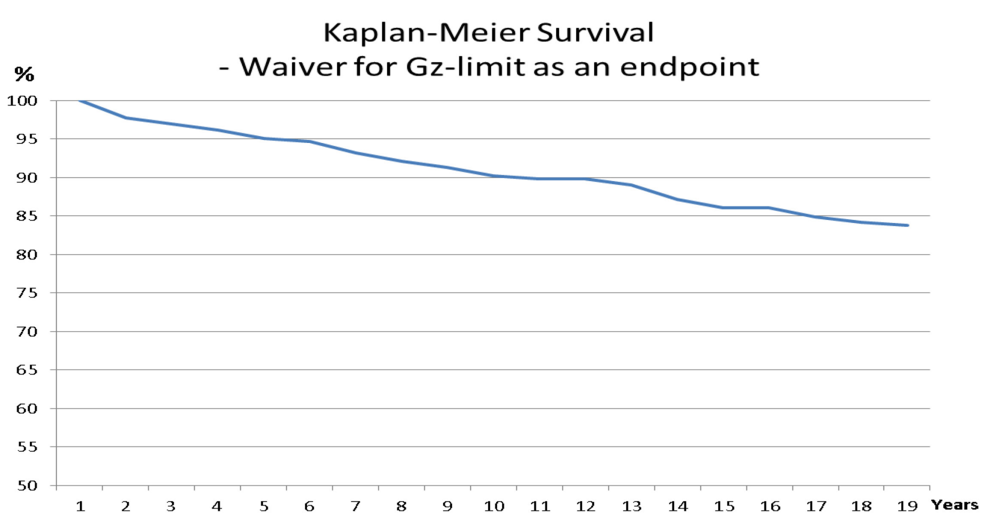

Figure 8-1: The Endpoint in Survival Analysis Was Set to the Date When a Pilot Was Waivered with Gz Limitation.

Note: Follow-up time started from the first jet trainer flight. Here all pilots who have started jet training between 1995 and 2015 were included in the survival analysis. (Data of FINAFCOM)

The US Air Force estimates that $2 million is spent on initial training for fast jet pilots. By the time they are fully mission capable, this investment could be as high as $10 million. For this investment it is expected that at least 10 years' service post-training is given, and for a pension 20 years' service is required. In Germany, training is estimated to be €2 – 3 million with similar lengths of service time expected. By cutting this service time short, the return on investment is severely reduced, even before consideration is given to any compensation for potential litigation.

8.2.2 Ranking Solutions

The solution cost/benefit question involves taking a second look at the possible solutions and formulating a conceptual ratio of the solution's efficacy per unit resources (cost and time to implement). We say a "conceptual" ratio because numbers simply do not exist on how effective any given solution is in reducing chronic neck pain. The solution's effectiveness can only really be found after implementing a solution and, perhaps after several years, determining future prevalence rates (pr) and comparing them to current prevalence rates. Conceptually, the solution efficacy could be calculated using Equation 8-1 as follows:

$$(\text{future pr} - \text{current pr})/\text{current pr}\ \% \qquad (8\text{-}1)$$

Alternatively, SMEs may be used to assess the efficacy of the solution to reduce neck pain based on their expertise and experience. In addition, SMEs may rank the solution based not only on their ability to reduce neck pain but also on the cost to implement the solutions. Potential costs are engineering or technical costs associated with integrating and maintaining the solution into operations, as well as performance costs associated with the solution being in operations. In some cases, a solution may reduce the risk of neck pain but aircrew performance may be compromised (e.g., helmet system support devices). On the other hand, one may have neck pain solutions that enhance performance (e.g., lighter helmet). This solution has a higher potential benefit per unit cost ratio than the former one.

8.2.3 Cost/Benefit Trade-Off Example

Canada has investigated both the causes of and solutions for Griffon helicopter aircrew neck trouble. Through the research conducted under this and other efforts, a total of twelve neck trouble mitigation solutions have been proposed and assessed:

1) Workload Distribution (Task Sharing and Biomechanically Advantageous Postures);
2) Smart Scheduling;
3) Helmet Fit;
4) Education;
5) Exercise;
6) Neck Supported Mass Study;
7) Helmet System Support Devices;
8) Multi-Function Display for Flight Engineer;
9) Multi-Function Display for Pilot;
10) CDU Position/Orientation;

11) Seat Ergonomics (better seat ergonomics integrated with displays and controls); and

12) Collective Ergonomics.

A systematic process was undertaken by DRDC to review, assess, and prioritise these twelve neck trouble mitigation solutions that seek to improve Griffon aircrew health and safety through technological, physiological, and task-oriented cost/benefit trade-offs (all the material in this example is taken directly from the contractor's report with permission from the contract technical authority) [3]. This process included reviewing the neck trouble mitigation solutions, deriving objectives and criteria to evaluate the neck trouble mitigation options, collecting ratings of these criterions from stakeholders and SMEs through facilitated data collection, and prioritising and assigning weightings of importance to each criterion using Multi-Attribute Utility Theory models.

Stakeholders included the RCAF Flight Surgeon (Canadian Forces Health Services Group Headquarters), personnel from the Director of Air Requirements, Director Technical Airworthiness and Engineering Support, CFEME, Griffon Helicopter Pilot and Flight Engineer SMEs, and scientists from the National Research Council (NRC) and DRDC Toronto Research Centre. A total of 25 individuals participated at the initial meeting.

After reviewing the solutions, SMEs settled on Medical Efficacy (i.e., benefit), Technical Feasibility (i.e., cost), and Operational Feasibility (i.e., benefit) as the three primary criteria to rank the solutions. Medical Efficacy was defined as the ability of the solution to prevent injury by reducing demands (i.e., amount of load and/or exposure time). Technical Feasibility included time, cost, ease to obtain an airworthiness certificate, and the technical readiness level of the solution. Operational Feasibility involved task universality and compatibility, training load, aircrew acceptability, and organisational modification complexity. The solutions were rated on 11-point scales (0 to 10) – one scale for each sub-criterion (there were a total of 18 sub-criteria) – where 0 was the worst value for that criterion and 10 was the best score in terms of efficacy and feasibility. Telephone interviews were conducted in two-hour blocks with a total of twelve stakeholders.

Table 8-1 presents the ratings first with respect to technical feasibility; specifically, time to implement, and then cost (these two dimensions were also rated by SMEs). Note that the Horizon and Cost Range are highly correlated ($R^2 = 0.85$). That is there are no solutions that have a low Horizon that is $100 M+ and vice versa. For 6- to 10-year horizons, the solutions are ordered with respect to cost between $11 M and $71 M. The Medical Feasibility and Operational Feasibility represent an average across all SME ratings and across all sub-criteria of the percent feasibility score. However, the correlation between Technical Feasibility and the Medical Efficacy and Operational Feasibility is $R^2 = 0.34$ and $R^2 = 0.03$, respectively. With this simple result one may imply that more expensive and longer time horizon solutions will generally produce gradually more effective solutions; however, the operational feasibility remains fairly constant at 82% regardless of the cost and time horizon.

Table 8-1: Prioritised Neck Trouble Mitigation Concepts Based on Time Horizon and Cost.

Rank	Neck Trouble Mitigation Concept	Horizon	Cost Range	Medical Efficacy (%)	Operational Feasibility (%)
1	Concept 4: Education	0 – 5 years	$0 – $2 million	60.6	86.5
2	Concept 5: Exercise	0 – 5 years	$0 – $2 million	52.5	81.5
3	Concept 2: Workload Distribution	0 – 5 years	$0 – $2 million	49.7	68.5
4	Concept 7: Neck Support Devices	0 – 5 years	$2 – $6 million	66.1	67.5
5	Concept 3: Helmet Fit	0 – 5 years	$11 – $16 million	50.9	92.0

Rank	Neck Trouble Mitigation Concept	Horizon	Cost Range	Medical Efficacy (%)	Operational Feasibility (%)
6	Concept 11: Seat Ergonomics	6 – 10 years	$11 – $16 million	60.3	88.0
7	Concept 6: Helmet Mass Properties	6 – 10 years	$16 – $23 million	70.3	97.0
8	Concept 1: Smart Scheduling	6 – 10 years	$23 – $31 million	52.5	55.0
9	Concept 12: Collective Ergonomics	6 – 10 years	$31 – $41 million	52.5	93.0
10	Concept 8: MFD for FE	6 – 10 years	$53 – $71 million	64.7	88.0
11	Concept 9: MFD for Pilot	10+ years	$100+ million	72.5	81.0
12	Concept 10: CDU Position/Orientation	10+ years	$100+ million	66.7	85.5

This study concluded that Education, Exercise, and Workload Distribution (task sharing and biomechanically advantageous postures) should be immediately implemented. The RCAF has begun to implement these solutions along with helmet fit and seat ergonomics, largely based on this cost-benefit analysis.

8.3 NECK PAIN FRAMEWORK AND SOLUTION INTEGRATION

There are other criteria that SMEs may want to consider as they step through solution integration. Recall the neck pain framework was a means for conceptualising possible factors that impact neck pain. In the same way, the neck pain framework may be used to categorise those solutions that address the possible factors. Table 8-2 links the main framework factors to the engineering and procedural solutions that HFM-252 was to investigate, and then to the specific solutions. The table implies that the proposed and recommended solution set addresses all of the neck pain framework factors, thus presents a complete and holistic solution set. At the same time, it is a very expensive solution set and it may take many years to implement. Human factors, Aircrew Behaviours, and Organisation-related solutions will likely be less expensive and require less time to implement. And therefore, these solutions would be a good first starting point for implementation.

Table 8-2: Categorising Preventative, Treatment, Procedural, Administrative, Engineering, and Ergonomic Solutions with Respect to the HFM-252 Aircrew Neck Pain Framework.

FRAMEWORK FACTOR	SOLUTIONS	
Human Factors	Preventative	Smart Scheduling Professional Athlete Model Aircrew Conditioning Programme Education Exercise
	Treatment	Professional Athlete Model
Body-Borne Equipment	Engineering	Lighter, more balanced, lower inertia helmet systems
	Procedural	Helmet Fit

FRAMEWORK FACTOR	SOLUTIONS	
Aircrew Behaviours	Procedural	Task Sharing Biomechanical Advantageous Postures
	Preventative	Exercise, Training
Workspace	Ergonomic	Redesign of controls, displays, and seats
	Engineering	Limiting G; mitigating vibration
Organisation	Administrative	Smart Scheduling
	Procedural	Limiting aircrew G exposure

8.4 A SYSTEMS APPROACH

Another perspective for consideration when implementing solutions is at a systems or organisational level. That is, solutions to the neck pain problem – whether administrative or mechanical – need to be carefully and systematically integrated into the overall organisation. The HSI discipline provides key considerations for integrating new components into existing systems that involve human work [4], [5].

For example, Ref. [6] surveyed 178 aircrew and found a relationship between posture-related symptoms and flight simulator use and computer use (not part of Aircraft Workspace yet still important to consider), implicating "computer vision syndrome" as a possible contributor to aircrew neck pain. As aircrew age and become dependent on presbyopic correction, poor cockpit geometry could certainly be a factor for flight surgeons to consider in the evaluation of neck symptomatology.

Also, it is important to consider the contributions of the psychosocial environment to the incidence, and recovery from, musculoskeletal problems in the cockpit (including neck pain). Australian fighter pilots, for example, were found to recover faster from in-flight neck problems when they had less deskwork [7]. Runeson-Broberg, Lindgren, and Norback [8] found associations between neck symptoms in the workplace and low social support, high work demands, and low supervisor support. While this study was based in a commercial aviation setting, the principles are generalizable to other aviation workplace environments.

Human systems generally comprise the operational environment, equipment system performance, and human system performance as shown in Figure 8-1 [9]. In an air force context, the operational environment is comprised of mission resources (aircraft platform, crew and support personnel, squadron operations, higher headquarters operations, training, doctrine, lessons learned, etc.) and external factors (adversary, weather, populations, political considerations, etc.). Equipment system performance refers to the efficacy of the system's mechanical and technology components (including the aircraft platform, thus the overlap in the Venn diagram) to assist the operator in accomplishing the mission goals. Human system performance focuses on the operator's ability to complete mission tasks accurately and in a timely fashion given the available goals, resources, and equipment.

One possible HSI process includes five domains that support the primary system functions as illustrated in Figure 8-2: Human Factors (i.e., human issues within the system), System Safety, Training, Health Hazards, and Personnel. Any neck pain solution can be filtered through each of these domains. The Human Factors domain attempts to optimise system performance by integrating knowledge of human characteristics to the design, development, and evaluation of solutions.

Health Hazards, in general, involves the elimination or reduction of any short- or long-term risks of injury, illness, or death. The neck pain solutions themselves address the HSI Health Hazards domain.

The System Safety domain identifies the risks of human or technology error and warrants that risk of failure is minimised in the design and operation of the solution. For example, a helmet system support device may be very effective in supporting the helmet. However, such systems may have cables attached to the helmet that present a snagging hazard. Thus, these devices must be redesigned to reduce the risk of snagging and increase operator safety during emergency ingress and egress.

Training is a critical HSI domain that often determines the effectiveness of the solution in operations. Training involves classroom instruction, education, part task training, and on-the-job training in order to provide the necessary knowledge, skills, and abilities required to apply the new neck pain solution. For example, a better "check 3" task may involve rotating from the trunk rather than the neck, and may be incorporated into existing training curricula, although trunk rotation may significantly slow down this task.

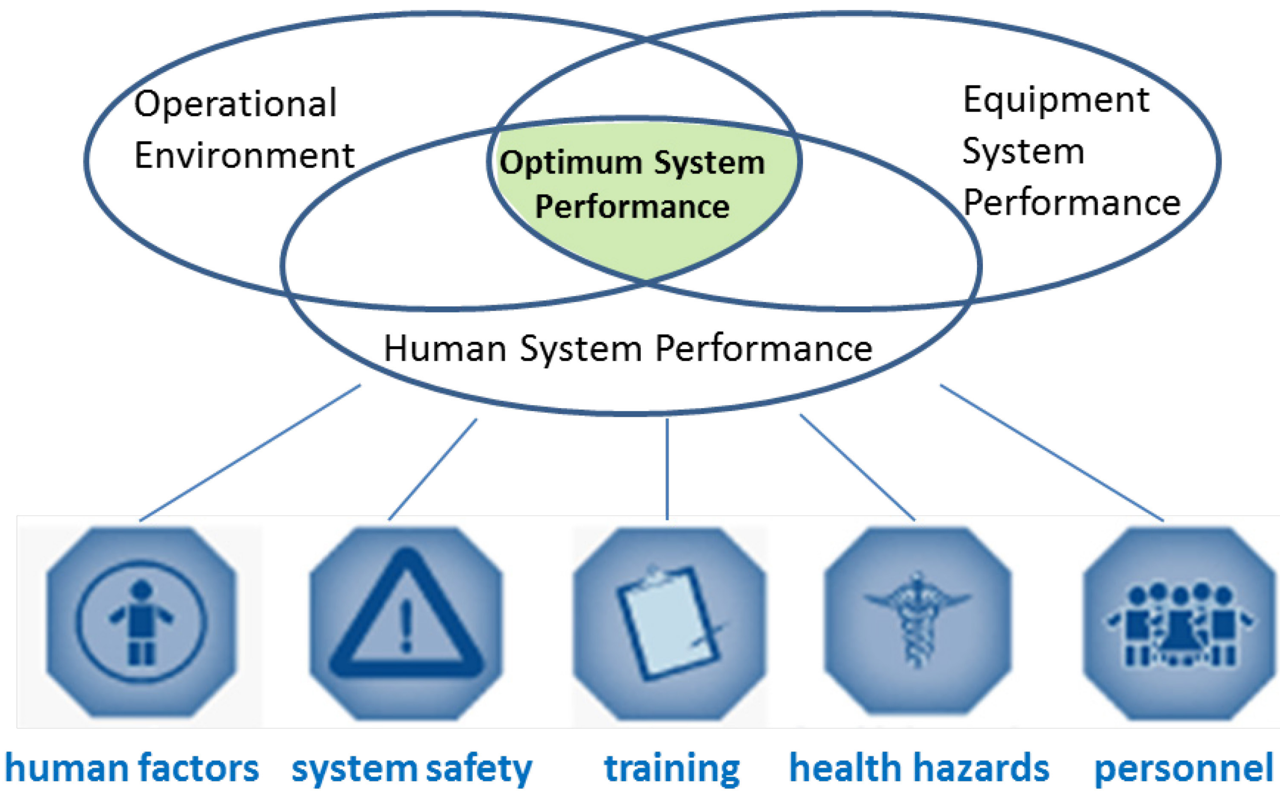

Figure 8-2: Five Domains of Human Systems Integration [6].

'Personnel' refers to the number, availability, and types of cognitive and physical characteristics aircrew candidates may need to maximise the solution's effectiveness: that is, aircrew selection. Neck pain is warning that an aircrew have exceeded their musculoskeletal system limits with health and performance implications and should not be ignored by the aircrew member or the support staff around them.

'Personnel' also refers to the organisation staff involved in mitigating aircrew neck pain. These personnel would include aircrew, clinicians, command, ALSE technicians, aircraft maintainers, procurement, and so on. Thus, neck pain mitigation should likely lead to changes in organisational mindset, behaviour, and culture.

We anticipate that there will be a number of solutions that will work together to minimise the risk of neck injury and pain in the future. Thus, HSI considerations apply to not only each solution independently, but also as a solution set. Moreover, there are efficiencies to be gained when considering the solution set in the context of the overall organisation.

8.5 ORGANISATION CONSIDERATIONS

Integrating neck pain administrative and engineering solutions into operations require cost-benefit trade-offs and organisational considerations. In the Canadian example, the solutions were ranked with respect to technical feasibility, medical efficacy, and operational feasibility. This allowed the RCAF to identify the selected high-priority solutions to be implemented. The HFM neck pain framework can be used to illustrate how a proposed solution set addresses the possible casual factors. Finally, the solution set may be filtered through key Human Systems Integration domains to ultimately optimise human system performance. The following is a list of considerations that may be helpful when integrating solutions into operations.

Consideration 8.1 (Sections 8.1 and 8.4): There is no single solution or 'quick fix' that will solve the aircrew neck pain problem. The solutions recommended in Chapters 3 to 7 must work synergistically, over time, to minimise the risk of developing or aggravating neck pain.

Consideration 8.2 (Section 8.1): Solutions should be implemented to prevent neck pain from the beginning of a military aircrew member's career and continue throughout one's career.

Consideration 8.3 (Section 8.2.1): NATO air forces seeking to implement the recommendations in this report must develop a business case, with cost-benefit analyses, to illustrate the benefits of long-term comprehensive solutions such as the Professional Athlete Model.

Consideration 8.4 (Section 8.4): Neck pain is a shared aircrew, clinician, and command problem. Thus, neck pain solutions may require a shift in organisational behaviour and culture.

Consideration 8.5 (Section 8.4): Neck pain is a warning that aircrew have exceeded their musculoskeletal system limits with health and performance implications. Therefore, it should not be ignored.

8.6 REFERENCES

[1] Fraser, W.D., Crowley, J.S., Shender, B.S., and Lee, V.M. (2015). Multinational survey of neck pain in rotor-wing aircrew, p. 24. TTCP Technical Report DOC-HUM-01-2015: The Technical Cooperation Program.

[2] Smith, A.M. (2016). The prevalence and operational significance of neck pain and back pain in Air Combat Group: IAM-2016-003-CR, Institute of Aviation Medicine – Adelaide, Adelaide, Australia.

[3] Tack, D.W., Bray-Miners, J., Nakaza, E.T., and Osborne, A. (2016). Griffon 2 Project: Assessment of revised work distribution for Griffon helicopter operator, p. 71. Toronto, Canada: Scientific Authority: Philip S. E. Farrell, Ph.D., DRDC-RDDC-2016-C224, Defence Research and Development Canada.

[4] AFHSIO. (2008). Air Force Human Systems Integration Office (AFHSIO) Handbook: Planning and Execution of Human Systems Integration. Directorate of Human Performance Integration Human Performance Optimization Division, Dayton, OH.

[5] Beevis, D. (1992). Analysis techniques for man-machine system design. Technical Report AC/243 (Panel 8) TR/7, North Atlantic Treaty Organization Defence Research Group: NATO, Brussels, Belgium.

[6] Mowry, C., and Ison, D.C. (2015). Assessing computer vision syndrome risk for pilots. The Journal of Aviation/Aerospace Education and Research, 24(2), 79-121.

[7] Tucker, B., Netto, K., Hampson, G., Opperman, B., and Aisbett, B. (2012). Predicting neck pain in Royal Australian Air Force fighter pilots. Military Medicine, 177(4), 444-450.

[8] Runeson-Broberg, R., Lindgren, T., and Norback, D. (2014). Musculoskeletal symptoms and psychosocial work environment among Swedish commercial pilots. Int Arch Occup Environ Health, 87(7), 685-693. doi: 10.1007/s00420-013-0911-8.

[9] Greenley, M., Salwaycott, A., Dyck, W., and Shaw, C.M. (2008). The development and validation of a human systems integration (HSI) program for the Canadian Department of National Defence (DND), p. 403. Ottawa, Canada: Scientific Authority: LCol Robert Poisson, DRDC-CR-2008-005, Defence Research and Development Canada.

CHAPTER 9 – SUMMARY, RECOMMENDATIONS, AND FUTURE WORK

9.1 SUMMARY

NATO RTG HFM-252 on Aircrew Neck Pain studied creative administrative, procedural, ergonomic, engineering, preventative, and treatment solutions to address aircrew neck pain either under development or that have been deployed amongst its member countries, and is now in a position to make recommendations.

Chapter 1 set the context for these investigations including the introduction of the neck pain framework for understanding possible causal factors of aircrew neck pain.

Chapter 2 presented a comprehensive literature review on the issues, neck pain and injury prevalence rates amongst various aircraft platforms, and operational impact as well as proposed a definition of significant flight-related aircrew neck pain.

Chapter 3 explored various assessments available for the investigation of neck pain including various modelling techniques, subjective and objective metrics, and proposed a set of common core questions for inclusion in all future neck pain questionnaires.

Chapter 4 studied human factors-related prevention and intervention programmes including education programmes, exercise programmes, work-rest cycles, restricting cumulative G exposure, treatment programmes, and aeromedical disposition.

Chapter 5 studied the impact of head- and body-borne equipment on aircrew neck pain and reported the results of helmet system mass studies.

Chapter 6 focussed on aircrew behaviours and tasks that identified the rationale to employ biomechanically advantageous postures during typical flight tasks to reduce neck loading whenever operationally possible.

Chapter 7 proposed various aircraft workspace solutions that improved workspace ergonomics as well as mitigated seat vibration.

Chapter 8 provided advice and guidance on integrating solutions into operations that may involve ranking solutions, ensuring solutions positively impact the possible causal neck pain factors, and considering a set of solutions through the lens of human systems integration domains.

All ToR objectives listed in Annex B were completed.

9.2 RECOMMENDATIONS

The following is a list of recommendations and guidance generated from Chapters 2 to 8. The recommendations in Chapters 2 and 3 focus on activities required to further understand aircrew neck pain. Chapters 4 to 7 provide a list of procedural, administrative, and engineering solutions to reduce aircrew neck pain. Chapter 8 provides organisational recommendations that are relevant to the aircrew neck pain problem.

9.2.1 Recommendations Towards Understanding Aircrew Neck Pain

Recommendation 2.1 (Section 2.3): This section has defined a series of terms that facilitates data collection and comparison across studies, which will enhance the ability to address the issues going forward. These definitions of a) Acute Pain, b) Sub-Acute Pain, c) Chronic Pain, d) Significant Pain, and e) Significant Flight-Related Pain should be used consistently when collecting data about neck pain.

Recommendation 3.1 (Section 3.1.2): Use of any model must be applied only for the conditions in which the model was validated. To determine its relevance to provide design guidelines for military purposes, users must know if the following apply to the question being asked (e.g., will this reduce neck pain incidence):

- Input data;
- The conditions the data were obtained under (temperature, humidity, loading magnitude, direction, onset rate, profile, etc.);
- Applicability to the population of interest (sex, age);
- Relevant loading vectors and postures;
- Appropriate use of animal surrogate data (scaling);
- Number of specimens used;
- The limitation of PMHS use for dynamic testing in which muscles are not active; and
- The availability of military-relevant validation data.

Recommendation 3.2 (Section 3.2.6): In order to close a gap in the ability to quantify aircrew pain and compare amongst aviators, development and validation of customised rating scales for aircrew, such as an aircrew-specific Neck Disability Index, would be helpful for healthcare providers who serve aviators in order to better and more quickly recognise complaints, identify the problem, and monitor the efficiency and effectiveness of treatment.

Recommendation 3.3 (Section 3.3.1): It is clear from the review in Chapter 2 of surveys that it is challenging to combine this data in meaningful ways. It is recommended that surveys are undertaken in a way that will allow for data to be consolidated across nations to increase statistical power, and facilitate population comparisons. Therefore, the NATO HFM-252 Aircrew Neck Pain Questionnaire should be included in all questionnaires to survey neck pain in an aircrew population. See Annex D for the NATO HFM-252 Aircrew Neck Pain Questionnaire for the recommended wording and format.

Recommendation 3.4 (Section 3.3.4): Questionnaires should include the twelve-month history of neck pain in all retrospective studies, and add additional questions with shorter/longer timeframes if indicated for the specific study. NATO RTG HFM-252 encourages the use of prospective studies whenever possible. If the purpose of the questionnaire is to measure the effect of specific changes in work environment (new equipment/aircraft) or interventions (neck pain prevention programmes), a prospective study should be used.

Recommendation 3.5 (Section 3.3.4): Conduct broad spectrum surveys of a given population no more frequently than every 5 years. This should be adequate time to allow any changes/interventions at the organizational level to show an effect. For specific interventions, questionnaires should be administered at baseline and again at more frequent intervals.

Recommendation 3.6 (Section 3.4.2): Besides the discussion about red flags in neck pain where imaging is an absolute necessity (see Section 4.5.1), if the sole symptom is acute neck pain, immediate imaging is not recommended due to the fact that MRI is expensive and there is only a limited correlation with the pain in most cases. Baseline imaging before high-G exposure is beneficial in order to evaluate later possible changes during the aircrew's career. Routine MRI follow-ups are not recommended for aircrew and it is suggested that the need for imaging be based on clinical outcome.

Recommendation 3.7 (Section 3.4.4): Procedures and conventions recommended in this report for the collection and analysis of EMG data should be followed by NATO neck pain researchers to facilitate collaboration and exchange of data.

9.2.2 Procedural, Administrative, and Engineering Solution Recommendations

Recommendation 4.1 (Sections 4.2.1 and 4.2.2): The overarching recommendation is that aircrew education focuses on a holistic, total lifestyle approach. Aircrew education in combination with all other solutions should lower injury risk.

Recommendation 4.2 (Sections 4.2.3, 4.2.4, and 4.3): A comprehensive multifaceted aircrew conditioning programme that includes enhanced physiotherapy support is recommended to all NATO air forces. Programmes should collect data that can be used later to determine effectiveness and cost/benefit of such conditioning programmes.

Recommendation 4.3 (Section 4.2.3): Several NATO countries are in the process of implementing some or all of the principles behind the Professional Athlete Model. It is recommended that countries pool their experiences and effectiveness data. Non-participating countries may monitor progress and consider implementation, if results from long-term practice are positive.

Recommendation 4.4 (Section 4.4): Extended rest as recommended by research and sports medicine experts may not be operationally feasible. However, when operations allow aircrew, especially those experiencing flight-related neck pain, should be allowed time to rest so that muscles can recover. In particular, work needs to be done to quantify the relationship between time of rest and quality of rest to develop an optimal balance between operational and physiological requirements. For example, while the mandatory 12-hour rest before a mission may be sufficient for cognitive recovery, depending on the non-flying activity performed, this may be insufficient for muscle recovery. Therefore, it is recommended that aircrew take the opportunity to rest their muscles whenever possible.

Recommendation 4.5 (Section 4.5.1): NATO air forces should invest in secondary prevention injury strategies in additional to the common practice of treatment. These include the following:

1) Initial intervention for acute problems should occur on the same calendar day or at the latest on the next calendar day. This requires a 24/7 on-call schedule for a physiotherapist or an alternate staff person, just as the flight surgeons may maintain.
2) Special training in aerospace medicine for staff that see the aircrew.
3) A physiotherapist or a similar occupation should deploy with the unit, just as the flight surgeon does.

Recommendation 4.6 (Section 4.6.6): Aeromedical disposition approaches for aircrew with neck pain should involve initial aircrew applicants, trained personnel, aeromedical summary, restrictions associated with treatment, gradual 'return to play' approach, follow-up, and suggested restrictions.

Recommendation 5.1 (Sections 5.2, 5.3, and 5.6): New helmet system procurement and design should ensure that the five key design principles – reduce helmet system mass, improve helmet system mass properties to achieve better balance, lower helmet system inertia, volume, profile, or bulk, achieve proper helmet fit, and ensure appropriate integration of helmet system with the rest of the ensemble – are considered in any procurement of a new system, thus considering the helmet system as a whole.

Recommendation 5.2 (Section 5.3): Aviation Life Support Equipment (ALSE) fit procedures should be reviewed and followed regularly to ensure that fitting is optimised.

Recommendation 5.3 (Sections 5.3 and 5.4): A proper helmet fit should be done during the initial fitting, whenever there is a change to the helmet system configuration, and at regular intervals. A proper helmet fit will decrease any slippage on the head (as well as reduce hot spots and pressure points, and increase comfort), and therefore reduce the amount of CW required for stability.

Recommendation 5.4 (Section 5.4): Given a proper helmet fit, the minimum Counterweight (CW) mass should be used that improves the stability and balance on the head. Counterbalance use for all aircrew should be reviewed when fit is assessed to ensure most appropriate CW is being used.

Recommendation 5.5 (Section 5.6): New helmet system procurement and design should take into account aircrew behaviours, tasks, postures, postural sequences, and physical movements (see Chapter 6 for more information).

Recommendation 5.6 (Section 5.6): New helmet system procurement and design should consider the integration of the new helmet system within the ALSE system, such as vests and G protection systems, as well as the cockpit and cabin (e.g., field of view constraints or affordances due to the head-borne equipment).

Recommendation 5.7 (Section 5.7): New helmet system procurement and design must consider all system requirements as shown in Figure 5-1, such as impact protection.

Recommendation 6.1 (Section 6.2.1.1): Task sharing should be explored where tasks that are likely to contribute to neck pain can be shared: i.e., for aircraft with more than one crew member.

Recommendation 6.2 (Section 6.2.1.2): Aircrew tasks that have been demonstrated as a likely contributor to increased risk of neck pain should be modified to include biomechanically advantageous postures.

Recommendation 6.3 (Section 6.2.2): Ergonomic handles and supports for rear crew should be used to promote biomechanically advantageous postures.

Recommendation 6.4 (Section 6.2.2): Aircrew tasks should be analysed to determine whether high-risk tasks can be redesigned, eliminated, or occur less frequently.

Recommendation 7.1 (Sections 7.4 and 7.5): In order to reduce neck load exposure, future workspace design should consider the potential for repositioning certain aircraft displays and controls to achieve more biomechanically advantageous postures.

Recommendation 7.2 (Section 7.6): For helicopters, track-and-balance maintenance and tuning should be performed regularly to reduce vibration at head level, thus minimising neck loading and muscle activity.

Recommendation 7.3 (Sections 7.6.1 and 4.2.2.5): For helicopters, crashworthy vibration mitigation cushions should be implemented to reduce vibration at head level, thus minimise neck loading and muscle activity.

Recommendation 7.4 (Sections 7.1 and 4.2.2.2.1.3): For fast jets, the medical disposition of the pilot should be determined on a case-by-case basis with mechanically and/or procedurally limiting high-G manoeuvres in non-deployed roles to a level in which the pilot remains asymptomatic until full function is restored, whenever operationally feasible, in order to prevent recurrent injury and ultimately reduce cumulative neck loading.

9.2.3 Organisation Considerations

Consideration 8.1 (Sections 8.1 and 8.4): There is no single solution or 'quick fix' that will solve the aircrew neck pain problem. The solutions recommended in Chapters 3 to 7 must work synergistically, over time, to minimise the risk of developing or aggravating neck pain.

Consideration 8.2 (Section 8.1): Solutions should be implemented to prevent neck pain from the beginning of a military aircrew member's career and continue throughout one's career.

Consideration 8.3 (Section 8.2.1): NATO air forces seeking to implement the recommendations in this report must develop a business case, with cost-benefit analyses, to illustrate the benefits of long-term comprehensive solutions such as the Professional Athlete Model.

Consideration 8.4 (Section 8.4): Neck pain is a shared aircrew, clinician, and command problem. Thus, neck pain solutions may require a shift in organisational behaviour and culture.

Consideration 8.5 (Section 8.4): Neck pain is a warning that aircrew have exceeded their musculoskeletal system limits with health and performance implications. Therefore, it should not be ignored.

9.3 FUTURE WORK

Future aircrew neck pain studies includes analysing data from organisations using the HFM-252-recommended neck pain survey (Core Questions), developing an aircrew-specific neck pain scale, validating electromyography standards, completing exercise studies, updating guidelines for aircrew helmet system mass properties, maturing seat vibration mitigation technologies, developing a template business case for aircrew neck pain solutions, and developing evidence to support the effectiveness of aircrew neck pain solutions in NATO air forces.

Additional research includes the applicability of advanced EMG collection and signal processing techniques for fatigue/pain research and biomechanical modelling including the use of multi-electrode arrays, time-frequency spectral analysis, frequency-wavenumber spectral analysis, and higher-order spectral analysis. Also, a task analysis should be carried out for fast jet aircrew to determine Aircrew Behaviour solution recommendations for this community.

Annex A – ROTARY-WING AND FAST JET SCENARIOS

This annex presents two composite scenarios that highlight various tasks that may lead to high neck loads. Note that the rotary-wing scenario moves from day to night, where aircrew will need to use NVGs, and the fixed-wing scenario can be flown either during the day or at night.

A.1 TACTICAL HELICOPTER MISSION PROFILE

A.1.1 Situation

The events described in this scenario could take place at any location within the Blue Air Force (a fictitious country's air force) sphere of responsibility. Temperature extremes could range from -30 to +40°C during both the day and night portions of this scenario.

This is a composite scenario in which the tactical scenario calls for a day mission followed by a brief respite and a night mission. The reader is introduced to a sample of differing manoeuvres based on the sample scenario.

A.1.2 Mission

Call sign Rotary Wing (RW) 21 has been requested to perform a day troop insertion at a prescribed landing zone followed by a night scenario in which troops will rappel onto a rooftop in order to secure a building.

A.1.3 Scenario

1200 RW 21 commences preparing for the insertion during both the day and night missions by creating and analysing tactical route maps.

1330 RW 21 completes the planning cycle, including loading route waypoints onto aircraft data cartridges and printing maps. Each of the two pilots and the FE review these mission materials prior to briefing in order to fully understand each phase of the mission.

1430 The Blue Air Force pilots and FE brief the leads in charge of the troops to be inserted on aspects of the mission. Troop commanders radio the troops in the field with any last-minute instructions.

1445 Pre-flight brief complete. All aircrew sign out aircraft and don ALSE equipment.

1500 Pilots and FE perform pre-flight aircraft inspections, strap in, start engines, perform pre-flight checks, and taxi for take-off.

1515 RW 21 completes its navigation to the target. (This includes a short high-level flight to a release point at which time the aircraft will be taken down to an altitude of 15 feet above highest obstacles for low-level navigation. The aircraft will land at a pick-up point to insert the troops into the helicopter and move them to a drop-off point. At the drop-off point the aircraft will perform a low-level reconnaissance of the landing zone to ensure adequate size/safety prior to landing.) During the entire low-level portion of the flight the pilots and FE will be turning their heads at least 120° looking over both shoulders. They will also be looking up and down at instruments and the landing sight, moving their heads at least 30° up and down at several points during the mission.

1645 Upon completion of the mission, RW 21 returns to the release point and executes a steep climb to a high level for the return flight back to the original departure point from the airbase. The high-level portion of the mission is necessary to avoid enemy small arms fire.

1700 RW 21 returns to the main airbase.

1710 All aircrew attend a post-flight and troop commander debrief. The mission is evaluated for its success, and issues (if any) are raised.

1740 Debriefing complete. The aircrew return to the crew rooms for rest/food.

1930 RW 21 completes the planning cycle, which includes loading route waypoints onto aircraft data cartridges and printing maps. Each of the two pilots and the FE review these mission materials prior to briefing in order to fully understand each phase of the mission.

2030 The RW pilots and FE brief the leads in charge of the troops to be rappelled onto building superstructures.

2045 Pre-flight brief complete. All aircrew sign out aircraft and don ALSE equipment, including 10 minutes to don and adjust NVGs and CW.

2100 Pilots and FE perform pre-flight aircraft inspections, strap in, start engines, perform pre-flight checks, and taxi for take-off.

2115 RW 21 completes its navigation to the target. (This includes a short high-level flight to a release point at which time the aircraft will be taken down to an altitude of 50 feet above highest obstacles for low-level navigation. The aircraft will approach the building for the troop insertion and come to a hover at approximately 80 feet above the rooftop.) During the entire low-level portion of the flight the pilots and FE will be turning their heads at least 120° looking over both shoulders. They will also be looking up and down at instruments and the landing sight, moving their heads at least 30° up and down at several points during the mission. While in the hover awaiting insertion by the troops, both pilots will be fixated outside the lower portion of the windows (looking down) at the two and ten o'clock positions in order to maintain a stable/stationary hover. This hover sequence could last up to five minutes to ensure the safe arrival of the troops that have rappelled onto the rooftop.

2230 Upon completion of the mission, RW 21 returns to the release point and executes a steep climb to a high level for the return flight back to the original departure point from the airbase. The high-level portion of the mission is necessary to avoid enemy small arms fire.

2245 RW 21 returns to the main ramp.

2300 All aircrew attend a post-flight and troop commander debrief. The mission is evaluated for its success, and issues (if any) are raised.

2330 Debriefing complete.

A.2 FIGHTER MISSION PROFILE

A.2.1 Situation

The events described in this scenario take place within about 100 Nautical Miles (NM) of a Blue Air Force base for a fighter pilot lead-in training course. The aircraft used is a single-engine high-performance jet trainer.

Aircrews report daily to the squadron at 0730h for weather and mission briefings. At 0800h the lead instructor for a planned formation of three fast jet aircraft (Zulu 21, 22, and 23) selects a target bridge about 60 NM north of Cold Lake for a simulated bombing mission. Zulu 21 & 22 (Zulus) will simulate friendly air forces and Zulu 23 is an enemy interceptor.

A.2.2 Mission

Zulus are tasked to simulate dropping a total of four Mk-82 low drag bombs on the bridge in order to disrupt an enemy ammunition supply route. Zulu 21 must plan the attack (delegating certain tasks to 22) with particular consideration to weather, terrain, and enemy threats. The mission objective is for the bombs to be dropped on the bridge at a time-on-target window of 2130h to 2140h. This mission may be performed day or night, where night missions would require enhanced night vision capabilities (i.e., NVGs).

A.2.3 Scenario

1830 Zulus commence preparing the attack plan and tactical route maps.

1930 Zulus complete the planning cycle, load route waypoints onto aircraft data cartridges, and print maps. Each of the six pilots (two per aircraft) reviews these mission materials prior to briefing in order to fully understand each phase of the mission.

1945 The Zulu 21 instructor pilot briefs aircrew on every aspect of the mission.

2030 Pre-flight brief complete. All aircrew sign out aircraft and don ALSE equipment, including NVGs.

2040 Aircrews board bus or walk to the aircraft ramp.

2050 Pilots perform pre-flight aircraft inspections, strap in, start engines, perform pre-flight checks, and taxi for take-off. Zulu 23 taxis and departs first in order to facilitate an intercept of Zulu 21 and 22 en route to the target.

2100 Zulus take off in echelon formation. Zulu 21's primary task is to navigate the formation while Zulu 22 follows 21. In order to visually follow Zulu 21, Zulu 22 must constantly keep his head and neck turned about 45° to the left while periodically cross-checking flight instruments to the front.

2110 Zulus reach 8000 feet Above Sea Level (ASL) and they break apart to a double attack formation (line abreast, 1.5 NM apart) for a weapon system and pilot G-tolerance check. Simultaneously each aircraft performs a 90° right turn at 4 G, a 180° left turn at the maximum G limit, followed by a 90° right turn at 4 G. Both aircraft then flip inverted for about 5 s to confirm there are no loose articles inside.

2115 Zulus ingress over simulated enemy territory in double attack formation while flying at approximately 10,000 – 20,000 feet ASL and 390 knots. They are now steering along the planned route to target. Prior to each turn, pilots do an exaggerated 360° lookout for enemy aircraft. During each turn pilots alternate between looking straight ahead and in the turn direction. Each en route turn is approximately 3 G.

2120 The Tactical Radar controller (SIDECAR) advises Zulus of an enemy bandit (Zulu 23) 30 NM to their 2 o'clock position. Zulus commit on the bandit by turning toward it. At 20 NM, Zulu 21 directs the formation to take lateral spacing from the bandit in order to achieve turning room for a fight. At 5 NM, Zulus scan the sky to get visual identification of the bandit. Once identified, Zulu 21 pulls 4 G to pass head-on with the bandit and engages in a turning fight. Zulu 22, further back from the fight, pulls 3 G in his turn, takes a missile shot, then proceeds to orbit the fight 3 NM laterally and 2000 feet above.

2125 Zulu 22 calls for 21 to disengage from the fight. Zulu 21 rolls wings level and pulls up at 3 G. He then unloads at 0 G to accelerate away from the fight and commences an orbit. Simultaneously, Zulu 22 dives from orbit into the fight and engages in a 4 G turn behind the bandit. Zulu 22 closes range behind the bandit to 2000 feet, pulls 5 G and snaps a gun shot. Meanwhile the bandit pilot is pulling 5 – 6 G, leaning far forward, and fully craning his neck backwards and upwards in order to remain visual with the Zulus.

2130 Zulu 22's gun shot is deemed as a valid kill and the fight terminates. Zulus then reform in double attack formation and head inbound toward the target.

2140 10 NM inbound, to create spacing from Zulu 21, 22 performs a 4 G turn perpendicular to the target, maintains this heading for 30 s, then turns back direct to the target. When each Zulu reaches 5 NM inbound, he turns to put the target 20° off the aircraft nose and waits until 2.3 NM. At 2.3 NM the pilot rolls toward the target in an almost inverted position (~ 130° of bank), pulls 3 – 5 G, and rolls out wings level in a 30° dive toward the target. At approximately 2500 ft above ground, the pilot simulates bomb release and pulls out of the dive at a G-onset rate of 4 G in 2 seconds.

2150 Zulus re-join into double attack formation and follow pre-planned routing back toward friendly territory. En route, Zulu 23 intercepts Zulu 21 and 22 again, and very similar mechanics to the first air-to-air fight ensue. The bandit is ultimately defeated and Zulus return to base in a 2-plane echelon formation. Zulu 23 follows behind.

2155 Weather at the base has deteriorated to 700 ft ceilings and 4 miles of visibility. All Zulus decide to complete vectored Instrument Landing System approaches.

2205 All aircraft land and park on the main ramp. Pilots take a bus back to the squadron.

2230 All pilots attend a debrief, using a computer programme which tracks each aircraft's position to assess shot validity, safety, and effectiveness.

2330 Debriefing complete.

Annex B – RESEARCH TASK GROUP ACTIVITIES

The specific RTG objectives are listed below as outlined in the Terms of Reference:

1) Expand a currently deployed preventive neck exercise study, led by US Naval Air Warfare Center Aircraft Division (NAWCAD), using a modified Swedish protocol, to a multi-nation effort. Canada, France, Germany, Portugal, and US Army are the participating nations/organisations. As Belgium and the Netherlands are also interested in implementing a preventive neck exercise programme in pilots and aircrew, they might also participate in this preventive neck exercise study. This effort will expand sample size, affording greater statistical power, and generalisability. Given the high prevalence of lower back pain in Belgian F-16 pilots, the specific neck exercise study is not enough. The Belgian Air Force would like to implement a multi-disciplinary preventive programme for their candidate pilots, entitled Aircrew Performance Enhancement Program, including a specific exercise programme "Fit4Pilot" (similar to Royal Air Force ACP); **Sections 4.2.4 and Annex E.**
2) Update and standardise prevalence/incidence survey tools which can be used across participating nations to collect aircrew neck pain incidence and prevalence data, thus affording the ability to discriminate across air forces, airframes; **Section 3.3** and **Annex D**.
3) Standardise electromyography procedures and analysis across participating nations, such that during planned multi-national human laboratory or in-flight biomechanics / head load studies, data may be directly shared and compared; **Section 3.4.4.**
4) Share helmet-fitting best practices and techniques (materials and methods); small adjustments may be inexpensive but highly effective in improving helmet fit; consequently mitigating the effects of off-axis helmet-mounted loading, minimising neck pain/injury; **Section 5.3**.
5) Collaboratively draft and publish a comprehensive literature review on neck pain, including the inclusion of data obtained from multi-national survey (above) into the paper; **Section 2.1**.
6) Share results and data used to validate finite analysis models of the neck and spine; **Section 3.1**.
7) Share best practices in aircrew recruitment and neck/back/spinal health screening, using either MRI or other methodologies; **Section 4.6**.
8) Collectively promote a 'professional athletic' model towards career management of aircrew, which focuses on a whole-human performance optimisation and modern health care focus through new research and publications / international defence science fora; **Section 4.2.3**.
9) Collaboratively investigate the feasibility of defining pain in the context of flight-induced / helmet mass-induced neck pain syndromes, and implementing an aircrew-specific disability index (an original piece or leveraged/adapted from other work); **Section 2.3.**

Other objectives that are implicit in the Terms of Reference include:

1) Identify and recommend specific administrative and engineering preventive solutions; **Section 9.2.2**.
2) Identify and recommend specific treatments for those already suffering from neck pain; **Section 4.5**.

Annex C – NECK PAIN CONCEPTUAL MODEL

C.1 CONCEPTUAL MODEL

A conceptual model that indicates possible neck pain causes is summarised in Figure C-1 [1]. This conceptual model for the causes of musculoskeletal complaints has five key elements given in Table C-1: Exposure, Dose, Response, Worker's Capacity, and Ergonomic Interventions. This conceptual model includes not only factors that produce short- and long-term effects on neck pain (such as work situation and exerted forces), but also how a solution might impact and mitigate the response (such as ergonomic interventions). Testable hypotheses can be generated from this model.

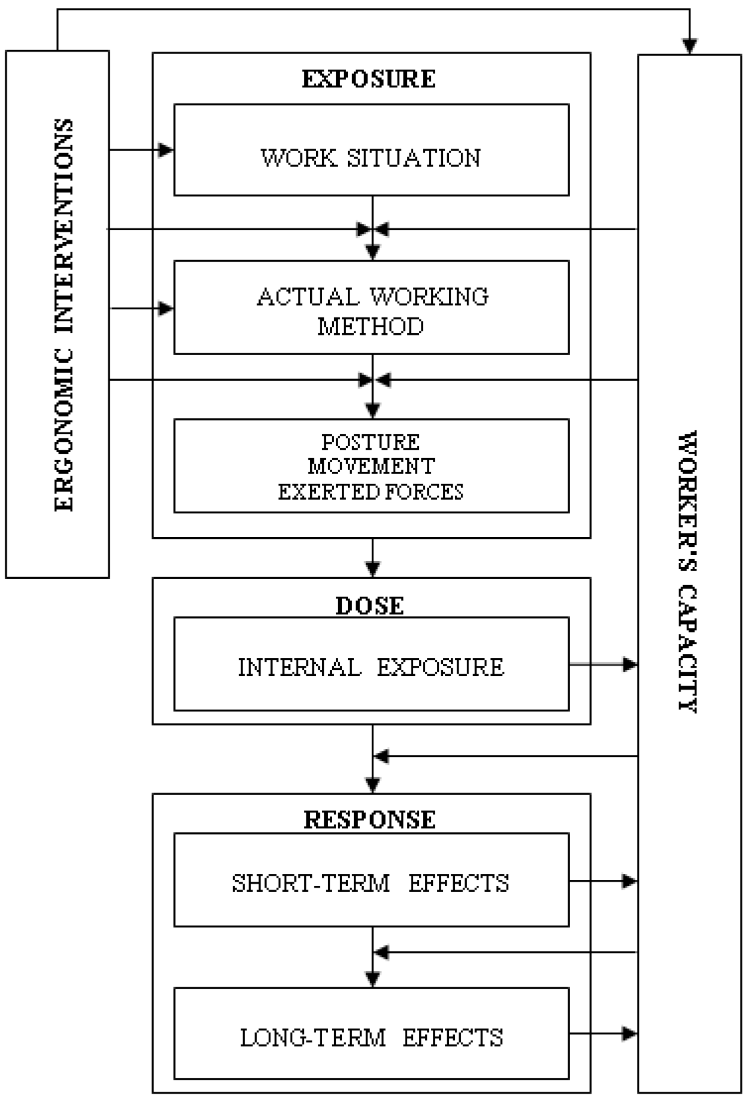

Figure C-1: Conceptual Model That Gives Insight into the Work-Relatedness of Musculoskeletal Complaints and Where to Intervene with Ergonomic Measures. (Based on [2], [3], and [4]). With permission from Dr. Marieke van den Oord, 21 April, 2015.

The main column of Exposure, Dose, and Response uses clinical terminology and provides a simple yet powerful lens looking at the problem. Table C-1 provides descriptors for each of the five main elements of the model. Note that Exposure alludes to task and posture demands of aircrew behaviours, Dose refers to moments and forces on the neck due to helmet system mass properties, Response highlights the pain and discomfort that is a result of the neck-supported mass and the task and posture demand, Worker's Capacity denotes individual characteristics such as fitness and anthropometry, and Ergonomic Interventions involves specific solutions that may alleviate neck pain. This framework also provides postulated influence links between the elements.

Table C-1: Definitions of the Concepts Used in the Conceptual Model Presented in Figure 1-2. With permission from Dr. Marieke van den Oord, 21 April, 2015.

Term	Definition
EXPOSURE	
Work Situation	The work demands and the task autonomy. The work demands are the tasks to be performed, including the tools and (personal protective) equipment, the work environment and the work conditions. The task autonomy involves the timing and method control which a worker may or may not have in the work situation [5].
Actual working method	The way the work is performed and characterised by, for example, work rate, utilisation of devices, lifting techniques, and number of breaks [6].
Posture, movement and exerted forces	The sequence of body postures, movements and exerted forces on the environment during work [6].
DOSE	
Internal exposure	Moments and forces within the human body; passive structures of the musculoskeletal system are exposed to internal forces along and moments around each of the three axes. With respect to active structures, recruitment patterns of muscles are generated to counterbalance net moments on motion segments caused by gravity, other external forces, and inertial forces [7].
RESPONSE	
Short-term effects	All temporary physical and mental responses to the internal exposure, such as changes in breathing frequency, feelings of fatigue, discomfort and pain during work and for some hours thereafter [8].
Long-term effects	All recurrent or permanent effects of workload on health, both positive and negative [6].
CAPACITY	
Worker's capacity	The physical, cognitive and mental characteristics of a worker. Examples are body dimensions, strength, expertise, age and sex. Although some characteristics are non-modifiable, such as height, the worker's capacity is a dynamic measure. Changes may occur in a short-term period, such as changes over the day caused by fatigue, as well as in long-term periods, such as increase or decrease in muscle strength over months or years [6].

Term	Definition
ERGONOMIC INTERVENTION	
	A change process initiated and implemented by a stakeholder with the aim of introducing measures that influence occupational mechanical exposures and/or acute responses in order to promote musculoskeletal healing [4].

Table C-2 lists the terms and concepts amongst the various models. Note that each framework, term, or model captures the full scope of the problem. Also note that the fourth column shows how the solution categories map onto the framework.

Table C-2: Comparing New Framework to ET-126 Terms, van den Oord's Conceptual Model, and Overall HFM-252 RTG Overall Objective Terms.

HFM-252 Framework	ET-126 Terms	Conceptual Model	Solution Category
HUMAN FACTORS Who Aircrew Are	Physical Therapy, Chiropractic, etc. Soft tissue Pathophysiology Biochemistry Defining pain	Worker's Capacity Dose (internal exposure) Response (long- and short-term effects)	Preventative Treatment
BODY-BORNE EQUIPMENT What Aircrew Wear	Helmet/HMD Engineering solutions	Exerted Forces	Engineering
AIRCREW BEHAVIOURS What Aircrew Do	Extreme postures Biomechanics	Actual Working Method Posture Movement	Procedural Preventative
WORKSPACE Where Aircrew Work	Cockpit Ergonomics Vibration Effects 'Glass cockpits' Remote cameras G-exposure Buffeting and Jolt Impact	Ergonomic Interventions	Ergonomic Engineering

HFM-252 Framework	ET-126 Terms	Conceptual Model	Solution Category
ORGANISATION Why Aircrew Fly	Administrative culture Operational Environment Frequent missions with fewer aircrew Helmet fitting	Work Situation	Administrative Procedural

C.2 REFERENCES

[1] van den Oord, M.H.A.H. (2012). Prevention of flight-related neck pain in military aircrew. (Doctor of Philosophy), University of Amsterdam, Amsterdam, the Netherlands. ISBN 978-90-804423-0-6.

[2] Van Dijk, F.J., van Domolen, M., Kompier, M.A., & Meijman, T.F. (1990). Reevaluation of the model workload-capacity [in Dutch]. Tijdschrift voor sociale gezondheidzorg, 11.

[3] Armstrong, T.J., Buckle, P., Fine, L.J., Hagberg, M., Jonsson, B., Kilbom, A., . . . Viikari-Juntura, E.R. (1993). A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scand J Work Environ Health, 19(2), 73-84.

[4] Westgaard, R.H., & Winkel, J. (1997). Ergonomic intervention research for improved musculoskeletal health: A critical review. International Journal of Industrial Ergonomics, 20, 463-500.

[5] van Veldhoven, M.J., & Sluiter, J.K. (2009). Work-related recovery opportunities: Testing scale properties and validity in relation to health. Int Arch Occup Environ Health, 82(9), 1065-1075. doi: 10.1007/s00420-009-0411-z.

[6] de Zwart, B.C., Frings-Dresen, M.H., & van Dijk, F.J. (1995). Physical workload and the aging worker: A review of the literature. Int Arch Occup Environ Health, 68(1), 1-12.

[7] van der Beek, A.J., & Frings-Dresen, M.H. (1998). Assessment of mechanical exposure in ergonomic epidemiology. Occup Environ Med, 55(5), 291-299.

[8] Hoozemans, M.J., van der Beek, A.J., Frings-Dresen, M.H., van Dijk, F.J., & van der Woude, L.H. (1998). Pushing and pulling in relation to musculoskeletal disorders: A review of risk factors. Ergonomics, 41(6), 757-781. doi: 10.1080/001401398186621.

Annex D – NATO HFM-252 AIRCREW NECK PAIN QUESTIONNAIRE

This annex contains the core Questionnaire questions. Adopting these core questions allows for the data (or analysis) to be grouped across nations' surveys, thus providing additional power to the analysis. (Note that items listed below in blue font and indented with an open circle bullet are explanatory comments and are not to be included in the administered questionnaire.)

NATO HFM-252 Aircrew Neck Pain Questionnaire

The <insert name of national organization administering the survey> is gathering information about neck pain and military flying in support of developing new personal protection and performance enhancement technologies and safety procedures. Our intent is to provide useful information to government and industry to improve future aircraft, helmet and life support equipment designs.

We would like to ask you about any past neck pain experiences and try to identify what factors might have caused the pain. We are particularly interested in flying-related causes of neck pain. If a question doesn't make sense or isn't letting you tell your story, please feel free to provide details in the margin or on the back of the questionnaire.

To understand flight-related neck pain, information from aircrew both with and without pain is important. Your responses will provide information about the factors which potentially contribute to neck pain and how common they are in the proportion of the population with and without pain.

Your participation in the survey is voluntary. However, your cooperation is encouraged so that the data will be complete and representative of all military aircrew. The information you provide will be treated in confidence and not be used as a basis for grounding or loss of flight status; rather it will be used to accurately capture the nature of the problem and help researchers and clinicians develop the most effective strategy to mitigate the pain and/or improve the situation.

If you have any questions, or would like further information, please contact <insert contact information of the national organization administering the questionnaire>.

Thank you for your cooperation.

DATE COMPLETED: ___________________

DEMOGRAPHIC INFORMATION

1. Age: ____________________

- Age = continuous variable
  - If you are testing a small population, asking for an exact age may make it too easy to identify the respondent. If this is the case, then allow the respondent to select age from the following options: 18-25; 26-30; 31-35; 36-40; 41-45; 46-50.

2. Sex

- Female
- Male

- If you are testing a small population, asking for sex may make it too easy to identify the respondent. If this is the case, then exclude this question.
- If your population does not include females you may exclude the sex question when appropriate.
- There are ethical issues around publishing identifying data; it may be important to collect this data, to identify outliers, etc., but you may not be able to publish the data in a way that identifies those individuals. The reviewing ethics board will make a determination, as per your organizational standards.

3. Height: __________ in OR __________ cm

4. Weight: _________ lbs OR __________ kg

5(a). What is your current primary position? Select only one.

- Student Pilot
- Instructor pilot
- Operational pilot
- Test pilot
- Demonstration pilot
- Non-flying (staff or administrative position)
- Staff or administrative position maintaining a minimum of flight hours
- Flight Engineer
- Load Master
- Crew Chief
- Other (please specify) __________________________

- Each questionnaire will need to be tailored to address specific organization/nation population/occupations of interest

5(b). If you are currently in a non-flying position, please indicate what your most recent flying position was. Select only one.

- Not applicable
- Student Pilot
- Instructor pilot
- Operational pilot
- Test pilot
- Demonstration pilot
- Staff or administrative position maintaining a minimum of flight hours
- Flight Engineer
- Load Master
- Crew Chief
- Other (please specify) __________________________

6. What is your current primary aircraft? If you are currently in a non-flying position, please indicate your most recent primary aircraft.

- CT-156/T-6 Harvard II
- CT-155 Hawk
- F-16 Falcon
- F-18 Hornet
- Eurofighter Typhoon
- Other (please specify)

  - Each survey will need to be tailored to address specific organization/nation population/aircraft of interest

PHYSICAL ACTIVITY

We would like to ask you about the types of activity that you are typically involved in.

1. During the past 12 months, how many hours (on average) have you spent in a seated_position performing computer/tablet/phone/office tasks, watching TV/playing games, etc., in a typical workday vs non-work day? (this excludes time in the aircraft)

Location	Work Day (hours)	Non Work Day (hours)
(a) At work	________________________	N/A
(b) At home	________________________	________________________

  - These two types of days will capture different things. For the purpose of designing potential intervention/mitigation strategies, it is important to differentiate between the time spent sitting at work vs at home, on typical work day vs non-work day.

2. During the past 12 months, how often (on average) have you participated in the following activities? Select only those that apply.

Activity	Every Day	2-5x /week	1x /week	1-3x /month	<1x /month	Never
Aerobic Exercise (e.g. running, cycling, swimming)						
Low Impact Activity (dog walking, gardening, etc.)						
Contact Sports (American football, football, hockey, rugby, boxing, MMA, etc.)						
Weight lifting / Strength Training						
Core / Stability Training						

Activity	Every Day	2-5x /week	1x /week	1-3x /month	<1x /month	Never
Flexibility Training / Yoga						
Specific neck exercises (Preventive exercises or therapeutic movements)						
Sport (Please specify):						
Other (Please specify):						

- It may be appropriate to separate each of these activities into specific questions, but this can be seen as leading or threatening way of asking how much time is spent doing each activity. Presenting the choices in a table format allows the respondent to answer all of them together as applicable.

FLIGHT-RELATED NECK PAIN

We would now like to ask you to describe the type of *Significant Neck Pain* you experience. For the following questions:

***Significant neck pain* refers to the presence of discomfort that intrudes into your awareness during your usual activities, and has caused you to perform at a lower level, continue despite discomfort, or modify your activity to reduce the discomfort. It *does not* refer to trivial mild aches that are easily dismissed and do not affect function.**

***Significant Flight-related neck pain* refers to pain that occurs during or within 48 hours after flight. It *does not* refer to pain that is obviously due to other activities or causes.**

- Time frame for recall is important and can be the limiting factor when comparing data between surveys.
- It is required to capture 12 month history as a minimum and if able/desired, also ask for 3 month history
- An important factor in timelines is that many flying units will conduct a cyclic flying schedule – e.g., night flying every 3 months – a 3 month history will capture this whereas a 12 month history may not

1(a). Have you experienced significant flight-related neck pain during or after flight in the past 12 months?

Yes _____

No _____

If No, please go to Question 4.

1(b). How long has your significant flight-related neck pain been present? Please provide a value (since your symptoms first began) in the appropriate text box.

_____ DAYS _____ WEEKS _____ MONTHS _____ YEARS

2. Please describe the symptoms associated with your significant flight-related neck pain experienced during or after flight. Select only those that apply.

• Stiffness or dull pain in neck muscles
• Stiffness or dull pain in back muscles
• Decreased range of motion in head and neck movements
• Sharp pain in neck muscles (with or without movement)
• Pain that radiates down upper extremity (shoulder, arm, elbow, wrist, hand, fingers)
• Decreased strength in upper extremity
• Neurological symptoms (numbness, tingling, weakness) in upper extremity
• Headache(s)
• Dizziness
• Nausea
• Fatigue
• Increased irritability
• Decreased focus or decreased concentration on tasks
• Other (Please specify) ____

- This question is very helpful in understanding the spectrum of symptoms that are related to neck pain and the many aspects of performance that can be affected.
- For clinicians making decisions on aeromedical disposition, understanding the symptoms associated with neck pain in a given population will enable a better understanding of the problem and the potential impact on the ability to conduct safe flight operations with neck pain.

3. How many episodes of significant flight-related neck pain during or after flight have you experienced during the past 12 months?

_________(please provide a number)

4. How long do the symptoms persist for a **<u>TYPICAL</u>** episode of significant flight-related neck pain experienced during or after flight? Please provide a value for the symptom duration in the appropriate text box.

a) During flight

_____ MIN _____ HRS _____

b) After flight

_____ MIN _____ HRS _____ DAYS _____ WEEKS

5. Please indicate the impact that a **TYPICAL** episode of significant neck pain experienced during or after flight has had on your ability to complete tasks safely by checking next to the appropriate statement:

(a) Before Flight

_____ no impact

_____ difficulty completing some tasks but **does not impact** safety

_____ difficulty completing some tasks that **begins to impact** safety

_____ unable/unsafe to fly/drive

(b) During Flight

_____ no impact

_____ difficulty completing some tasks but **does not impact** flight safety

_____ difficulty completing some tasks that **begins to impact** flight safety

_____ unable/unsafe to fly

(c) After Flight

_____ no impact

_____ difficulty completing some tasks but **does not impact** safety

_____ difficulty completing some tasks that **begins to impact** safety

_____ unable/unsafe to fly/drive

6. Please indicate the impact that the **WORST** episode of significant neck pain experienced during or after flight has had on your ability to complete tasks safely:

(a) Before Flight

_____ no impact

_____ difficulty completing some tasks but **does not impact** safety

_____ difficulty completing some tasks that **begins to impact** safety

_____ unable/unsafe to fly/drive

(b) During Flight

_____ no impact

_____ difficulty completing some tasks but **does not impact** flight safety

_____ difficulty completing some tasks that **begins to impact** flight safety

_____ unable/unsafe to fly

(c) After Flight

_____ no impact

_____ difficulty completing some tasks but **does not impact** safety

_____ difficulty completing some tasks that **begins to impact** safety

_____ unable/unsafe to fly/drive

- It is important to differentiate between typical and worst episode because they could be two very different values. Many people have low-grade chronic pain with occasional very intense acute-or-chronic episodes. This tells a different story than someone who has very intense chronic pain.
- It is also important to understand the degree to which pain impacts performance. By asking about the impact of pain on one's ability to complete tasks (such as driving) safely, before and after flight (as well as during) we can better understand how debilitating the pain is.

FLIGHT EXPERIENCE

We would now like to ask you about your military flying experience. Please use your logbook to complete the following questions.

- Use of a logbook is preferred, but for the purposes of this questionnaire, aircrew recollection of their flight hours is generally accurate enough to negate the absolute requirement for logbooks [1], [2].

1. How many years have you been flying as military aircrew? ______________________

2. Please provide your total military flying hours: ______________________

3. **Beginning with your current primary aircraft** and working back through your flying career, please specify the types of aircraft you have flown and provide the TOTAL hours logged on that type.

Aircraft Type:	Total Flying Hours:
• ______________	______________________
• ______________	______________________

• ________________ __________________________

• Other (specify): _____________ __________________________

4. Please provide the number of day and night hours you have flown in your **current primary aircraft:**

	In the past 12 months	Typical sortie length
• Day Flying Hours	___________	___________
• Night Flying Hours	___________	___________
• NVG Flying Hours	___________	___________
• JHMCS Hours	___________	___________
• Other Head Mounted System (HMS) (Day) Flying Hours	___________	___________

Please specify HMS: ___________

• Other Head Mounted System (Night) Flying Hours	___________	___________

Please specify HMS: ___________

Many aircrew only fly daytime hours with JHMCS and/or only fly night time hours with NVGs. So, day hours may equal JHMCS hours and night hours may equal NVG hours. However, as this is not always the case, and the additional flight time spent wearing increased HSM can be a significant contributing factor to neck strain, it is important to ask these questions separately in some populations (students in particular, who may not be using JHMCS or NVG yet).

REFERENCES

[1] Smith, A.M. (2018a). Accuracy of flying experience estimated by aircrew: IAM-2018-004-TR, RAAF Institute of Aviation Medicine, Adelaide, Australia.

[2] Smith, A.M. (2018b). Accuracy of flying experience estimated by aircrew. Paper presented at the Aerospace Medical Association, Dallas, TX.

Annex E – COLLABORATIVE EXERCISE STUDIES IN PROGRESS

1. **Canada:** Based on a protocol developed by Hébert, Roy, Burke, Côté, and Grodecki in 2012 (unpublished work), which was derived from Ref. [1]:

   a. The aim of this study was to evaluate the efficacy of a modified Äng specific neck/shoulder exercise regimen in the prevention and reduction of neck pain in subjects in a flight billet. This included RCAF helicopter pilots and flight engineers using a single-blind randomized clinical trial. After obtaining their informed consent, subjects were randomly assigned to one of two groups: the first group received a slightly modified exercise programme derived from Ref. [1] over an 8-week period, while the second group continued their normal activities and training. (See Figure E-1.)

   b. Participants were evaluated on four separate occasions: at baseline (week 0), 8 weeks, 6 months, and 12 months. In addition, all participants were asked to maintain a weekly web-based log book about the type of helicopter flown in the past week, total flying time, flight hours with and without night vision goggles, exercises performed, as well as neck pain experience during the past week related and unrelated to flying (athletic, non-flight activities, and sleeping), level of maximum and average pain, and treatment received. All participants completed this web-based log book online each week.

   c. The baseline evaluation included completion of a series of questionnaires involving sociodemographic information, symptomatology, and comorbidity. Prevalence of neck pain was scored using the Nordic Musculoskeletal Questionnaire [2], [3] and the Neck Disability Index [4] was used to rate neck pain related to physical limitations and restrictions. Cervicothoracic range of motion, neck muscle strength and neck muscle endurance were determined using a Multi-Cervical Unit (MCU) (BTE Technologies, Inc., Hanover, MD, USA). This was repeated at 8 weeks, 6, and 12 months.

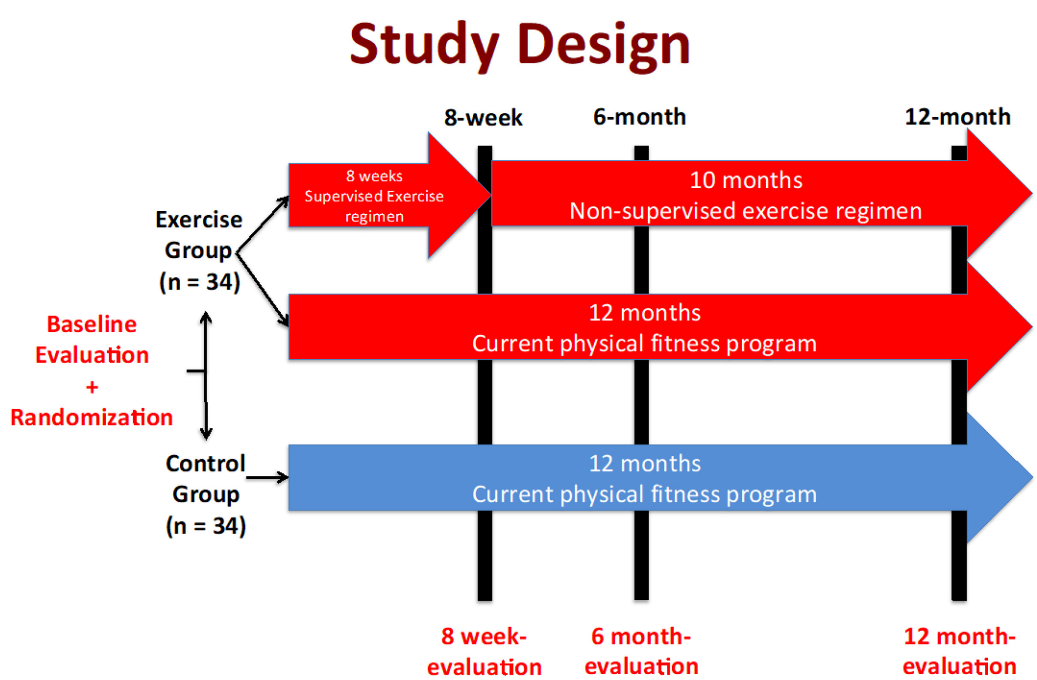

Figure E-1: Study Design of the Canadian RCT.

d. Exercise group: Intervention:

i. Participants in the Exercise group took part in an 8-week exercise regimen programme based on the programme developed by Ref. [1]. A physiotherapist (PT) supervised the exercise regimen weekly with individual sessions. Participants who reported pain in the last three months were asked to perform the exercises twice daily, while those reporting no pain during the previous 3 months or on flying days were asked to perform the exercises once daily.

ii. The supervised session lasts 10 to 15 minutes, which includes the learning and performance of 2 – 4 exercises. The programme allowed the participants to perform the exercises independently of any clinic or stationary equipment at the gym, at home, or at the base. Written instructions accompanied with pictures illustrating the exercises and a Digital Versatile Disc was provided. Exercises were individually dosed and progressed by the supervising PT. Progression was from non-postural to postural to load-situated exercises, moving largely from isolated low-load muscle exercises to synergy endurance-strength exercises. Guided by the PT, the progression was based on the participant's observed progress towards neck/shoulder motor control and movement quality, rather than on a certain amount of sets and repetitions. Progression led to initial exercises being replaced with new exercises, thus the number of exercises performed did not increase through the intervention period.

iii. Here is a description of the Hébert et al. protocol, a modified exercise protocol [1]:

1. *Non-postural Exercises:* With the subject supine, active craniocervical flexion is targeted at deep prevertebral neck muscles, largely the longus colli and capitis. The superficial neck flexors, particularly the sternocleidomastoid muscles that flex the lower cervical spine but extend the upper cervical joints, are not activated. Initially, the participants are instructed and manually guided to perform accurate craniocervical flexion while trying to focus on maintaining surface neck flexors relaxed. Then, they practice controlling and holding low-load increment levels of craniocervical flexion with feedback from an air-filled pressure sensor (Stabilizer, Chattanooga Group, Hixon, TN, USA) behind the neck. The supervising physiotherapist monitors potential surface flexor activity visually, with palpation if necessary. Contraction of the deep prevertebral muscles straightens the cervical lordotic curvature and this shows as an increase in pressure (mm Hg) on the sensor display unit. Active scapular retraction exercises aimed to target scapular muscles, particularly the trapezius, rhomboid, and serratus anterior. Initially these muscles are guided and trained by emphasizing control and holding at an inner and midmotion range in prone position.

2. *Postural Situated Exercises:* Participants are taught to sit upright on a stool in a comfortable, neutral lumbar-lordosis posture and first perform isolated and controlled, low-load increments of active craniocervical flexion and shoulder retraction separately. Synergy exercises are trained by simultaneously performing scapular retraction, craniocervical flexion, and neck rotation, with short holds within the inner rotation motion range. Participants with ongoing pain start with low-load neck rotator isometric resistance exercise.

3. *Endurance-Strength Exercises:* Participants practice controlled, dynamic shoulder retraction in rowing exercises, here emphasizing the initiation of scapular retraction in the early concentric phase and upright neck/thoracic postures in the inner motion range. Dynamic neck rotation exercises are performed against moderate rotatory resistance using elastic rubber bands (Theraband, Hygiene Corp., Akron, OH, USA) in seated position. These exercises are intended to train co-contraction including flexor and extensor muscles. Holding the rubber band between the teeth and anchored between hands and a wall, the subjects first slightly nod the head, extend

the head slightly and then gently rotate it. Neck flexor isometric endurance are trained supine by first nodding the head and then lifting it a few centimetres from the surface against gravity (for 30 seconds or until perceived exertion was "strong", i.e., 5 on the Borg Category Ratio-10 scale). No high-load/maximal-load neck exercises are included, particularly since air force helicopter pilots and flight engineers with prior neck pain, as opposed to fighter pilots, have shown altered myoelectric patterns rather than loss of neck strength.

e. Control group: Participants in the control group are asked to continue their current physical fitness programme without specific intervention. Control participants are asked to maintain the weekly logbook and undergo re-testing at 6 and 12 months.

2. **Australia, Canada, US (Air Force, Army and Navy):**

a. The metrics and procedures (RCT with exercise and control groups) for this study are basically the same as the Canada modified Äng study, except that the MCU is not used to assess CROM and neck strength/endurance (see Figure E-2 for Study Flow Chart). CROM is measured using a handheld goniometer. Subjects have their height, weight, head circumference, head width, neck circumference at mid-cervical spine, base neck circumference including trapezius musculature, sitting height, and overall neck length (measured from occiput to T1) measured. The exercise intervention and endurance assessment is performed using the NeckX® device (NeckX Systems, Aspen, CO, USA http://neckxsystems.com/).

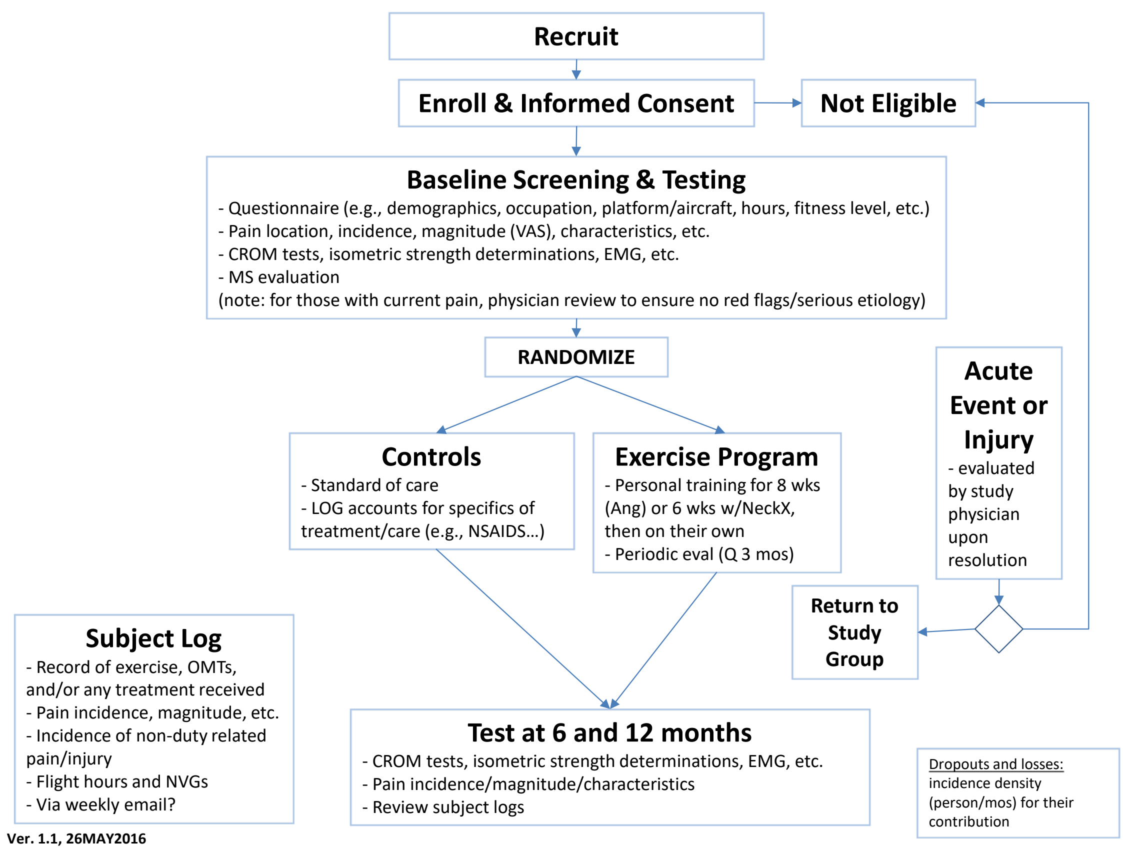

Figure E-2: Study Flow Chart.

i. NeckX® is a lightweight, portable neck exercise device that stretches and strengthens neck musculature to increase flexibility and stamina, reduce the likelihood of injury, relieve pain and improve mission effectiveness. The NeckX® system consist of a fleece cap with size adjustments, chin strap and multiple levels of exercise resistance bands +/- safety wrist loops that are provided to facilitate increased resistance training. These bands are easily switched and can be fixated to target specific muscle groups (see Figure E-3). Recommended exercises are provided to target the cervical musculature most commonly related to neck muscle strain.

Figure E-3: NeckX® Device with Bands and Being Employed During Exercises.

b. Exercise group: NeckX® Intervention:

i. *Warm-up* (All warm-up exercises, except for Side Bending and Neck Rotation, should be performed with 3 second hold in each direction of motion with a slight pause at neutral for a total of slightly more than 6 seconds per repetition. Side Bending and Neck Rotation exercises should come to neutral end position after movement to the left/right sides.):

a. Neck Retraction: 10 reps x 1 set.

b. Neck Extension: 10 reps x 1 set.

c. Side Bending: Left – 5 reps x 1 set Right – 5 reps x 1 set.

d. Neck Rotation: Left – 5 reps x 1 set Right – 5 reps x 1 set.

e. Neck Flexion: 10 reps x 1 set.

ii. Neck-X® Stretches (All exercises, except for Side Bending and Neck Rotation, are performed with 3 seconds of pull to maximum range of motion, slight pause at neutral, and followed by 3 seconds of engaged resistance for a total of slightly more than 6 seconds per repetition. Side Bending and Neck Rotation exercises should come to neutral end position after movement to the left/right sides.):

a. Neck Retraction / Chin Tucks: 10 reps x 2 sets.

b. Neck Extension: 10 reps x 2 sets.

c. Side Bending: Left – 10 reps x 2 sets Right – 10 reps x 2 sets.

d. Neck Rotation: Left – 10 reps x 2 sets Right – 10 reps x 2 sets.

e. Neck Flexion: 10 reps x 2 sets.

f. Optional Exercises:

(1) 45° Check to Back: 10 reps x 2 sets.

(2) 45° Check to Back: 10 reps x 2 sets.

(3) Vertical Lifts: 10 reps x 2 sets.

iii. Guidelines:

a. All participants begin with the yellow (lowest) resistance band.

b. Regimen is to be performed 5 days/week.

c. At the end of each week, participants proceed to the next band level (green, followed by purple). Note: If the participant feels pain, excessive fatigue, etc., then an additional week is spent on the current resistance band.

d. After the week of exercises using the purple band, the subsequent weeks' regimen will include 2 sets of 15 reps of each exercise since range of motion and strength have been developed in the preceding weeks.

e. Optional exercises to be incorporated one per week after step d, and in the order of: (1) 45° check back, (2) 45° check down, and (3) vertical lifts. The optional exercises are performed for 10 reps x 2 sets.

iv. Measurements:

a. Pre-measurements are to be performed before the study.

b. Mid-measurements are to be performed typically after the 3rd week of the programme, at which time the participants have completed one week with the yellow, green, and purple bands. However, not all participants may progress sequentially, so mid-measurements may be performed at whichever point after 3 weeks when the participant has reached the end of the week with purple band exercises at 10 reps per set.

c. Post-measurements are to be performed after 6 weeks. At this time, the participant typically has completed the core exercises at 10 repetitions per set for 3 weeks with each of the three resistance bands, followed by completing 3 weeks of exercises using the purple band for 15 repetitions per set, and may have begun incorporating the optional exercises. However, not all participants may progress sequentially, so post-measurements may be performed at whichever point after 6 weeks when the participant has reached the end of 3 weeks with the purple band exercises at 15 reps per set.

d. All measurements are to be taken in the same sequence as the warm-up exercises.

v. Preliminary results with Neck-X® [5]:

a. Following Institutional Review Board approval, 6 subjects (5 males, 1 female) underwent a 12-week exercise programme using the Neck-X® cervical stretching and exercise device 3x/week. Mean baseline and post-programme measurements of cervical strength (resistance), endurance (repetitions), and ROM (goniometer) were obtained. Subjects completed weekly logs to assess pain frequency and magnitude (0 – 10 scale) and document contributing factors.

b. Mean strength increased: flexion (+104%), extension (+57%), lateral bend (+50%), and rotation (+47%). Mean endurance increased: flexion (+142%), extension (+157%), lateral bend (+170), and rotation (+217%). Mean flexibility increased: flexion (+17%), extension (+36%) lateral bend (+23%), and rotation (+63%). Subjects reported reduced severity and frequency of neck pain in weekly logs.

3. **US Air Force Viper Neck Health and EXercise Strategies (NHEXS) Program** [6]**:**

   a. Pre-flight Strategies:

      i. Neck Strengthening:

The two primary pre-flight warm-ups include isolation neck muscle strength and ROM exercises. Although neck muscle strength has been investigated by several experts in the field, their results regarding its effectiveness in preventing neck strain remain inconclusive. Nonetheless, most researchers suggest that specificity and intensity of neck strength training offer some degree of neck protection encountered during high G [7]. In fact, good neck and muscle strength and endurance may act more as a preventative measure against perceived neck discomfort post-flight [8] . It is recommended that a neck muscle strengthening and endurance programme be performed three times weekly for 6 months, coupled with 5% to 10% bi-weekly workload progression based on the subject's adaptations. It is suggested that pilots perform four sets of 10 repetitions per neck strengthening exercise [8]. Nonetheless, the programme should ultimately be tailored based on individual adaptation and be supervised [8]. This type of progression may result in reduced risk of neck injuries [7], [8], [9]. Additionally, there may be a relationship between neck size and strength in providing some protective benefit to supporting cervical structures while under G stress, ultimately resulting in reduced muscle strains and injury to the neck region.

The fundamental movements of the spinal column are flexion, extension, lateral flexion, and rotation. The greatest amount of movement takes place in the cervical and lumbar regions due to the position of the ribcage in the thorax region. In the neck region, the major muscle groups are the sternocleidomastoid, the scalene, and deep prevertebrals. Additionally, the muscles that make up the prevertebrals are responsible for flexing and rotating the spine. The scalene muscles have a unique function because they not only laterally flex the neck, but during forced respiration, they elevate the first three ribs, allowing for lung expansion [10]. The primary muscles involved in flexion (chin to chest) and extension (chin up) of the neck are considered the strongest, followed by the muscles involved in lateral movement of the neck (e.g., bending ear to shoulder); the muscles involved in neck rotation (e.g., looking side to side) are the weakest.

Most in-flight manoeuvres may force the neck into positions that require a combination of neck rotation, extension, and lateral bending (e.g., check-six). The combination of movements places the neck and its supporting tissues in a position that may cause neck strain (shear stress).

Training the neck musculature can be difficult based on the hard and soft tissue structures of the neck muscles and their various movement patterns. Additionally, it can be very difficult to isolate the weakest link in the neck muscles' chain (e.g., muscles responsible for neck rotation).

Popular forms of neck strengthening options could include:

1. The 4-way neck machine. This machine is acceptable for training the muscles responsible for flexing and extending the neck. The 4-way neck machine targets the neck muscles from various angles. However, it does not include a movement to train the muscles responsible for rotating the neck.
2. The neck harnesses allow for more natural movement patterns compared to the 4-way neck machine. However, when using the neck harness, you must exercise caution by using proper exercise form, since this is a free-weight training device. Without incorporating proper neck-lifting mechanics when using the neck harness, you are more prone to neck injury. Nonetheless, the neck harness allows you to strengthen the neck from various positions to include frontal flexion, left and right lateral flexion, and extension.

3. Exercise bands or towel work can be awkward to perform and places limitations on the types of neck movements that can be performed. Using a towel to strengthen your neck will allow you to perform movements such as the chin lift and isometric forehead press that target the muscles located on the front of your neck. Nonetheless, performing towel neck strengthening exercises can be awkward, and workload progression is difficult to manipulate.
4. Another neck strengthening approach uses a headband which attaches to the resistance source. Some have an inflatable cushion; models of these include the Halo and Iron Neck – we will refer to these as Inflatable Headband Systems (IHSs). The IHSs have been reported to outperform many other neck strengthening devices primarily because they target the neck muscles through the entire 360° ROM with a scalable weight load; in addition, they target the neck muscles responsible for lateral flexion and extension.

Neck strengthening uses the Halo IHS, 3 to 5 minutes daily, using horizontal rotary resistance. Because rotation of the neck is cited as a key lead-in to an acute pain event, the rotary movement is warranted when training the neck musculature.

Performing 5 to 10 minutes of stretching exercises for the neck and thoracic spine region coupled with various ROM exercises may provide some protective benefit [11]. However, this is not a universal finding [10]. Normal ROM of the neck may be sufficient for high-G flight, and proper neck strengthening exercises will likely contribute to increased ROM. Nonetheless, ROM about the neck musculature can be reduced due to the aging process. Neck ROM generally deteriorates by an estimated 4° per decade after age 30 [7].

A recommended pre-flight neck warm-up with some ROM work may provide some protection during high-G manoeuvres. Because higher demands are placed on the cervical and thoracic spine while flying high-performance aircraft, the neck muscles are significantly strained during flight; therefore, a pre-flight neck warm-up may ameliorate some of the neck strain incurred during high-G manoeuvres. Any type of physical training regimen/workout should be preceded by an active warm-up to help prepare skeletal muscle for higher intensity work. Hence, the muscles of the neck should not be treated differently. The active warm-up does not have to be extensive and should take between 5 to 8 minutes to complete during pre-flight operations or while travelling to the military operating area.

b. ROM Pre-Flight Warm-Up:

For each of the pre-flight warm-ups, move through the plane of motion (e.g., flexion, extension, lateral flexion) at least 5 to10 times. Avoid deliberately forcing through a ROM, especially if you experience any unusual musculoskeletal pain (as with a hand pressing helmet) beyond what you can achieve simply moving through natural ROMs.

1. Side to side bending (ear to shoulder).
2. Flexion and extension (chin to chest, chin up).
3. Rotation (look side to side).
4. Rotation + extension to both sides (check-six) and lateral bending.

c. In-Flight Strategies:

Some researchers suggest significant neck injury rate differences between F-16 pilots who habitually anchor their body position and place their helmet against the seat prior to G onset and those who do not [8]. Additional differences have been found between those who deliberately unload G to properly reposition as opposed to repositioning while under high G [11]. These findings are consistent with broader conclusions that movement of the neck while under G (especially multi-planer movements like going from a check-six position over the left shoulder to over the right shoulder while under high G) is highly hazardous to the neck.

A suggested in-flight strategy is to use the cockpit structure to support the helmet while under G and to achieve that helmet placement prior to G onset. It is unrealistic to not move the head while under G. However, any effort to unload and reposition could result in reduction on the cumulative wear and tear on the neck. Additionally, when movement under G is required, minimise concurrent movement in multiple planes of motion (i.e., rotation and flexion). If possible, focus on movement in one plane of motion at a time. For example, when recovering from the check-six position, laterally flex the neck and then rotate.

d. Post-flight Strategies:

A post-flight neck battle damage check is advisable. Early recognition of significant neck/spine injuries is crucial to positive final outcomes. Surveys of fighter pilots have found rest, heat/cold therapy, sleep, massage, and nonsteroidal anti-inflammatory drugs (i.e., Advil) to be beneficial for minor neck injury recovery and for minor symptom relief. Some anecdotal claims support chiropractic and acupuncture treatments for symptom relief. Nonetheless, there apparently is limited research-based data to support these modalities.

For severe neck injury cases, surgical intervention is an option. An estimated 90% of fighter pilots who require a single-level diskectomy or fusion can obtain a waiver for continued service. However, any surgery involving two vertebral levels is permanently disqualifying.

However, proper pre-flight and in-flight strategies will minimise the requirement for aggressive symptom relief and/or surgical intervention.

e. Neck Strength Conditioning Guide:

i. *Purpose and Intent:*

The goal of this neck strength conditioning guide is to increase the size and force production capability of the neck muscles responsible for neck flexion, extension, and rotation. The neck musculature has the ability to withstand continual low intensity work, as it can support your head for many hours without fatiguing [12]. Training of the neck musculature should follow the general strength and conditioning principles of specificity, volume, overload, and progression. It must be noted that for most people, these muscles are not accustomed to significant overloading (especially the muscles involved with rotation). Therefore, it is prudent to begin with very light loads and progress conservatively with training loads and volumes.

Once significant gains are achieved, workloads should still remain fairly low. For example, unlike squats, which require recruitment of very large skeletal muscle groups, neck muscle strength training requires recruitment of long, thin, and fairly delicate muscles that are not accustomed to daily physical training or overload. Therefore, when starting this neck strengthening programme, proceed with caution and ensure your programme is supervised by a trained professional.

For training contact your local designated Point of Contact (may be an Aerospace Operational Physiologist, Physical Therapist, Flight Surgeon, or other health professional). The movements and techniques for this programme are quite unique, and some simple instruction is required. **If significant neck pain or problems already exist, seek the guidance of a flight surgeon prior to commencing any neck training.**

ii. *Warm-Up:*

Ensure the cable attachment point is 1 inch below Halo level. Ensure the bottom of the Halo aligns where a pair of glasses would sit above your ears. Inflate the Halo to achieve a comfortable but secure fit. Use of the chin strap is optional. However, it does improve the security of the Halo.

With minimal resistance and deliberate full range of motion movements:

LLLR = look left, look right with a stationary torso
QT = quarter turn

LLLR facing front, side, back, side
Locked neck, spin in place 5 spins each direction
A 'figure eight' facing front and back
10 quicker LLLR at each QT
Slow spin in place with 10 LLLRs
1 minute rest prior to continuing

iii. *Halo Neck Strengthening Workout:*

1. LLLR with QT:
   a. Start by facing the cable attachment point. While keeping torso stationary, move cranium directly left and right with slow, deliberate, full range of motion movements.
   b. 12 reps each QT.
2. The Spin: Spin in place with neck stationary, 6 turns each direction.
3. The Spin with LLLR: Complete 6 revolutions each direction while completing 6 LLLRs.
4. Multiple 'figure eights':
   a. Draw an infinity symbol with your nose.
   b. 12 reps facing cable, 12 facing away from cable.
5. Quick Rep LLLR with QT:
   a. 12 quick LLLR reps at each QT.
   b. Keep torso rigid, as you will tend to involve more body movement as the neck muscles fatigue.
6. 2-minute rest.
7. Locked Neck Body Turns:
   a. Add additional resistance.
   b. With locked neck, rotate upper body 90° at each QT while in the athletic stance.
   c. 12 reps each QT.
8. Check-Six:
   a. Drop resistance to load from steps 1 – 5.

   b. Facing attachment point, look down toward left shoulder then high above right shoulder for 12 reps. Reverse to look low right / high left.
   c. For side positions only do low (shoulder close to attachment) to high.
   d. Repeat facing away.
9. Locked Neck Body Turns:
   a. Increase resistance over step 7.
   b. With locked neck, rotate torso through 90° from athletic stance.
   c. 12 reps each QT.
10. Slow LLLRs (advanced only; only after 6 – 9 weeks of training): Using max weight, do 12 reps LLLR at each QT.

4. Italian Air Force:

a. Motivation: Italy identified comparable physical exercise programme to CAN and US protocols, in order to reduce the risk to develop neck pain in military aircrew and possibly improve the clinical condition in pilots suffering cervical disorders, pointing out possible physical dysfunctions that could cause them. Pursuant to the Italian air operational considerations and available funding and according to the therapeutic approach developed in previous studies [13], [14] it was decided to focus attention on re-educating muscular activity, mobility and coordination between different muscular areas. The purpose was to avoid strengthening exercise by resistance bands and use only body weight exercise and stability training through isometric contraction to improve strength and endurance in cervical muscles.

b. Approach:

   i. We identified our target in Eurofighter 2000 fighter pilots in order to test this programme in subjects exposed to very high-G load. We selected two groups located in two different bases (case-control) similar by age, flight hours and physical fitness.

   ii. A group of 20 Eurofighter (EFA) pilots (mean age 36.25) at an air force base received weekly encouragement to perform every other day (at least three times per week) for two months a specific exercise program consisting of Deep Cervical Flexor (DCF) muscles training, core and shoulder stability and re-education of cervical and postural system. The programme allowed the participants to perform the exercises independently of any clinic or stationary equipment at the gym, at home, or at the base. Written instructions accompanied with pictures illustrating the exercises and a DVD was provided. Exercise adherence in EG was monitored using diaries.

   Exercises were individually dosed and progressed by the supervising PT.

   Every training session last roughly 15 minutes.

   The control group of 21 EFA pilots (mean age 32.95) from another air force base kept doing their routine physical activity without specific intervention.

   Inclusion criteria consisted in having logged flying hours during the previous 2 months, while exclusion were based on those suggested by Ref. [1]: participants with previous cervical or upper thoracic spinal surgery, neurological symptoms, significant limitations and restrictions because of a neck problem, participation in a neck training program during the past year and any other physical\medical condition that could be exacerbated by the exercise regimen.

iii. The intervention period and test/retest periods were the same as the CAN and US protocols. Participants have been tested at baseline (week 0) and at the end of the programme (week 8).

Aircrew Neck Pain Survey was used to collect data about neck pain related to flight activity.

Neck Disability Index (NDI), Baecke Questionnaire and Numeric Pain Rating Scale (NPRS) have been used to measure functional disability, physical activity and the level of pain respectively.

Metrics were similar to CAN and US protocols, but the instrumentation was different.

CROM has been measured by the iPhone Digital Compass Application.

In order to analyze cervical muscle function, the Muscle Endurance Performance (MEP) tests have been performed. These consist of Neck Flexor Endurance Test (NFET), Neck Extensor Endurance Test (NEET) and Cranial Cervical Flexion Test (CCFT). NFET and NEET have been performed using the iPhone Digital Compass Application while for CCFT has been used the STABILIZERTM Pressure Bio-Feedback (Chattanooga Group, Inc.).

iv. Exercise intervention:

1. Poses derived from yoga:

These improve the increasing awareness of the upright and correct posture, the normalizing of breathing patterns, as well as the stretching of both frontal and dorsal fascia [15].

a. ***Cat-cow yoga stretch*** 8 – 10 breaths:

It involves moving the spine from a rounded position (flexion) to an arched one (extension). In quadruped position, inhale and tilt your pelvis back for cow pose, then exhale and tuck your tailbone for cat pose.

b. ***Cobra position*** 20 – 30 sec:

Start from the resting yoga "child pose", kneeling back on heels with the upper body over the thighs and the forehead onto the floor, arms long and extended, lie down flat on your stomach, place the palms flat on the ground directly under shoulder and inhale to lift your chest off the floor, rolling shoulder back and keeping neck neutral.

2. Core stability:

a. ***Rock-back quadruped extension/rotation*** 8 – 10 – 12 repetitions for each side:

This exercise increases T-spine mobility with minimal low back involvement; the degree of rotation depends on the level of mobility of the back. Getting down on hands and knees with arms, shoulder-width apart and hands directly underneath shoulder. Place one hand on the nape with arm parallel to the ground, bring the elbow flexed upwards inhaling and flex the elbow downward to the resting arm exhaling.

b. ***Bird Dog*** quadruped with alternate arm/leg raises 3 series with 5 sec alternating sides then 10, finally 15 sec to 90 sec:

It specifically engages the multifidi, the deep transverse spine stabilizer and extensor of the lumbar spine. On all fours bracing the abdominal wall, while maintaining a midrange/neutral curve of the lumbar spine, raise the right arm and the left leg (opposite upper and lower limbs) into a line with the trunk. The goal is to maintain lumbar stability while the opposite arm and leg are raised slowly [16], [17].

c. ***Planks and Bridging*** 10 sec for each position – 20 sec – 30 sec:

Prone and side plank are fundamental, static core-stability exercises designed to challenge the subject's body against gravity in the coronal/frontal plane and are ideal exercise to train the abdominals and quadratus lumborum. Bridging is a fundamental core-stability and gluteal strengthening exercise [16], [18]. From push-up positions (prone plank) to side-support position on the both elbows (side plank) and then the rear-support position (bridging).

3. Shoulder mobility and upper back strengthening exercises:

a. ***Prone shoulder circuit for shoulder reinforce (Y, T, W)*** 2 sets with 8 – 16 repetitions, no rest between each position:

It targets trapezius and rhomboids that stabilize shoulder blades; it also strengthens rotator cuff and all of muscles essential for good posture. Lying prone on the floor or on a bench, Y portion of the exercise is done by holding arms up to form a Y shape perpendicular to the ground; T portion is done by laterally raising both arms out to the sides. For Y and T letter thumbs pointed up. The key to T position is to retract the scapula and maintain a 90° angle at the shoulder. The angle should never be less than 90°, which indicates latissimus dorsi substitution. W portion of the exercise is done with shoulders at 45 – 60° to the body and elbow fixed at 60 – 90°. The subjects must move the arms by moving the scapulo-thoracic joint, not the reverse [18].

b. ***Wall slide*** (forward wall slide or sitting Indian-style wall slide) with head rotation 30 – 60 sec:

These activate the low trapezius, rhomboid ad external rotators, stretch the pectorals and internal rotators and decrease the contributions of the upper trapezius. It trains dynamic scapular stability upward rotation and scapular stability for retraction and depression. Hands and wrist are flat against the wall, during the slide up the forearms press into the wall. Rotate the head on both sides at the start and end position of the arms should associate neck mobility during arm movement [19]. The subject needs to be able to move the gleno-humeral joint in the presence of a stable scapula (the essence of shoulder health). Scapulae are retracted and depressed.

4. Specific DCFm training and proprioception:

a. _***DCFm muscle training*** 8 repetitions for 10 sec, 10 x 10 sec, 15 x 10 sec, 15 x 15 sec (vd. Canadian programme).

It involves retraining a static holding contraction of the target muscles. DCF exercises are performed with the subject's hip joints and knee joints flexed. Towels are placed between the subject's head and floor to reduce friction while the patient is lying down. To contract the longus colli and longus capitis, the jaw was pulled down to make a nodding movement [20].

b. ***Proprioception of neck*** one technique for cervical alignment treatment is placing a book atop the subject's head (change the weight and size of the books to improve the capacity), to help him assume a more erect posture, thus taking stress off the posterior joints. Subjects have to walk or rotate the head during this procedure from 20 secs to 1 min [21].

5. Stretching:

   a. ***Pectoral stretching*** 2 sets of 30 sec on both sides:

      The muscles of upper backs keep the shoulders back, but may find great resistance against the strain of the shortened, tight chest. Pectoral muscle stretching should improve this condition.

      Stand in a doorway lined up with the opening, place arm at shoulder height in the doorway upward at 45° angles and, keeping spine straight, rotate body away.

   b. ***Neck Stretching*** 20 secs at least for each static position:

      Poor posture, weak muscles and limited CROM could affect neck pain. Simple stretches may help decrease poor posture and neck pain. Stretching exercises should be performed slowly in a controlled manner, avoiding to force to the point of pain; stretching should provide relief.

      (i) Flexion/extension: chin towards chest, hold, head back, hold.

      (ii) Lateral flexion: ear towards right shoulder while looking straight ahead and hold, switch side.

      (iii) Head rotation: turn head right and look straight, hold, switch side.

      (iv) Upper trapezius stretch: turn head right and chin towards armpit, switch side.

      (v) Levator scapulae stretch: turn right, ear towards chest, switch side.

v. Pilot Study Results:

1. We found in the whole group of pilots (41 subjects) a moderate relation between number of flight-related neck pain events in the three months previous the study and age (r = .595), years of activity (r = .541), height (r = .563), flying hours (r = .597) and EFA flying hours (r = .494). Furthermore, a moderate relation between the intensity of the flight-related "worst neck pain" in the same three months and previous flying experience on F-16 (r = .553) was found.

   We experienced a very poor compliance from pilots; just seven of those included in the training group completed the 2-month training programme.

   The training group showed no statistically significant improvement in CROM, nor difference in MET (both flexors and extensors) after training. No differences related to neck pain were found between groups. However, the pilots who performed the postural training reported subjective relief in executing it.

2. In conclusion the postural exercise training proposed was not effective in improving neck functionality (CROM, MET), nor to reduce neck pain and improve clinical conditions. Due to the duration of the intervention and the constant duty required to the pilots, several subjects failed in accomplish the task and this significantly reduced the sample. Further studies with higher number of pilots and a better compliance would be desirable.

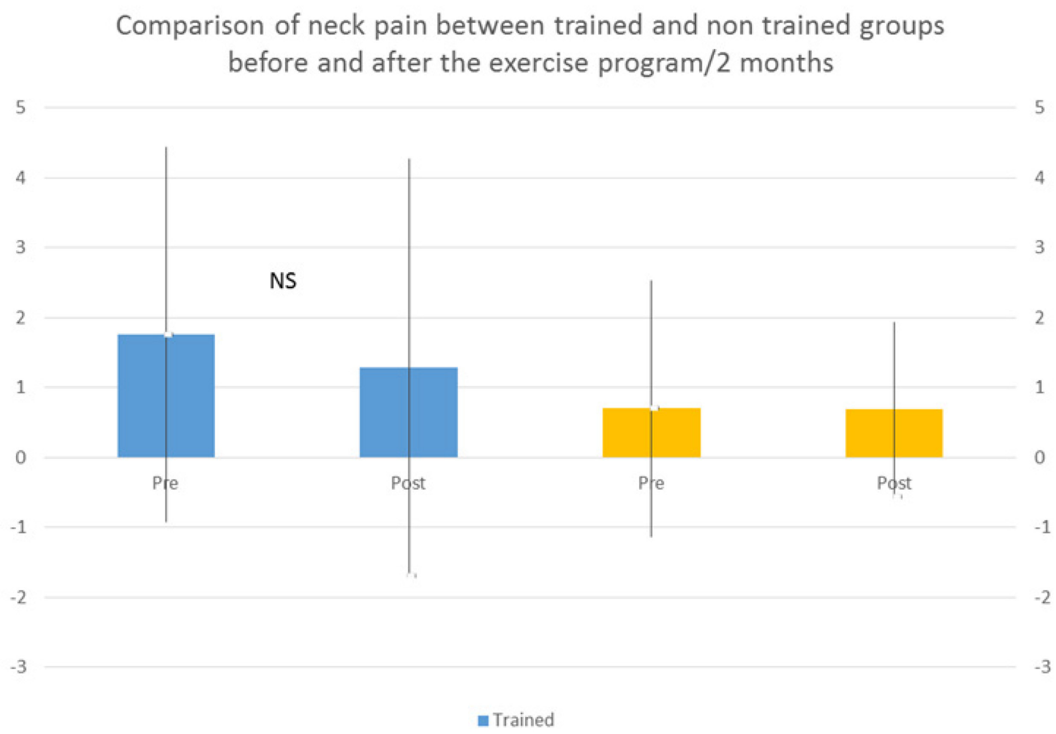

Figure E-4: Mean Number of Neck Pain Episodes Between Trained and Non-Trained Groups.

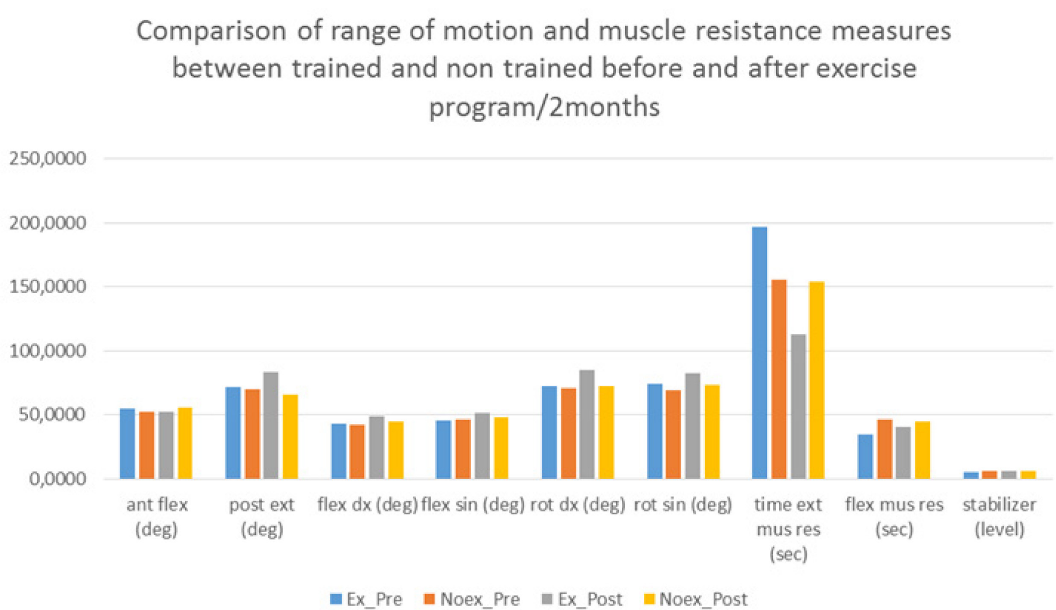

Figure E-5: Comparison of Range of Motion (Degrees), NFET (Seconds), NEET (Seconds) and CCFT (Level of Stabilizer) Between Trained and Non-Trained Groups Before and After the 2 Month Exercise Programme.

REFERENCES

[1] Äng, B.O., Monnier, A., and Harms-Ringdahl, K. (2009). Neck/shoulder exercise for neck pain in air force helicopter pilots: A randomized controlled trial. SPINE, 34(16), E544-E551.

[2] de Barros, E.N., and Alexandre, N.M. (2003). Cross-cultural adaptation of the Nordic musculoskeletal questionnaire. Int Nurs Rev, 50(2), 101-108.

[3] Dickinson, C.E., Campion, K., Foster, A.F., Newman, S.J., O'Rourke, A.M., and Thomas, P.G. (1992). Questionnaire development: An examination of the Nordic musculoskeletal questionnaire. Appl Ergon, 23(3), 197-201.

[4] Vernon, H., and Mior, S. (1991). The Neck Disability Index: A study of reliability and validity. J Manipulative Physiol Ther, 14(7), 409-415.

[5] Ramachandran, V., Jones, J.A., Scheuring, R.A., Ramakrishnan, R., Filler, R.D., Perry, C.M., . . . Baskin, D. (2017). Exercise regimen for mitigation of acute and chronic pain in military aircrew. Aerospace Medicine and Human Performance, 88(3), 343.

[6] Sarsfield, S., O'Hara, R., and Wright, B.A. (2012). Viper NHEXS (Neck Health and EXercise Strategies) Program: A Viper Pilot Neck Health and Conditioning Guide: AFRL-SA-WP-SR-2013-0001, Wright-Patterson Air Force Base, Dayton, OH.

[7] Chen, J., Solinger, A.B., Poncet, J.F., and Lantz, C.A. (1999). Meta-analysis of normative cervical motion. Spine (Philadelphia, PA, 1976), 24(15), 1571-1578.

[8] Seng, K.Y., Lam, P.M., and Lee, V.S. (2003). Acceleration effects on neck muscle strength: Pilots vs. non-pilots. Aviat Space Environ Med, 74(2), 164-168.

[9] Burnett, A.F., Naumann, F.L., and Burton, E.J. (2004). Flight-training effect on the cervical muscle isometric strength of trainee pilots. Aviat Space Environ Med, 75(7), 611-615.

[10] Behnke, R.S. (2006). Kinetic Anatomy 2nd ed. Champaign, IL: Human Kinetics Inc.

[11] Green, N.D., and Brown, L. (2004). Head positioning and neck muscle activation during air combat. Aviat Space Environ Med, 75(8), 676-680.

[12] Alricsson, M., Harms-Ringdahl, K., Larsson, B., Linder, J., and Werner, S. (2004). Neck muscle strength and endurance in fighter pilots: Effects of a supervised training program. Aviat Space Environ Med, 75(1), 23-28.

[13] Falla, D., Lindstrom, R., Rechter, L., Boudreau, S., and Petzke, F. (2013). Effectiveness of an 8-week exercise programme on pain and specificity of neck muscle activity in patients with chronic neck pain: A randomized controlled study. Eur J Pain, 17(10), 1517-1528. doi: 10.1002/j.1532-2149.2013.00321.x.

[14] Jull, G.A., Falla, D., Vicenzino, B., and Hodges, P.W. (2009). The effect of therapeutic exercise on activation of the deep cervical flexor muscles in people with chronic neck pain. Man Ther, 14(6), 696-701. doi: 10.1016/j.math.2009.05.004.

[15] Liebenson, C. (2008). Postural correction. J Bodyw Mov Ther, 12(4), 318-319. doi: 10.1016/j.jbmt.2008.06.010.

[16] Fredericson, M., and Moore, T. (2005). Muscular balance, core stability, and injury prevention for middle- and long-distance runners. Physical Medicine and Rehabilitation Clinics of North America, 16, 669-689.

[17] Liebenson, C. (2010). The missing link in protecting against back pain. J Bodyw Mov Ther, 14(1), 99-101. doi: 10.1016/j.jbmt.2009.10.002.

[18] Boyle, M. (2003). Functional Training for Sports. Champaign, IL: Human Kinetics.

[19] Boyle, M. (2010). Advances in Functional Training: Training Techniques for Coaches, Personal Trainers and Athletes. Aptos, CA: On Target Publications.

[20] Cheung, S.H., Her, J.G., Ko, T., You, Y.Y., and Lee, J.S. (2012). Effects of exercise in deep cervical flexors in patients with chronic neck pain. Journal of Physical Therapy Science, 24, 629-632.

[21] Morningstar, M.W. (2003). Cervical hyperlordosis, forward head posture, and lumbar kyphosis correction: A novel treatment for mid-thoracic pain. J Chiropr Med, 2(3), 111-115. doi: 10.1016/S0899-3467(07)60055-X.

Annex F – DETAILS OF NATIONAL EDUCATION PROGRAMMES

F.1 DESCRIPTION AND RATIONALE OF THE ITALIAN PREVENTIVE EDUCATION PROGRAMME

1. Italian educational programme for pilots and flight staff consists of lessons provided during aero-physiological training courses in the Aerospace Medical Division of Flight Experimental Centre in Pratica di Mare AFB. All the Italian military pilots and flight staff attend these courses that include training in hypobaric chamber, spatial disorientation, and night vision.

2. There are different types of courses depending on the experience of pilots: basic one-week training for young pilots from the Military Academy, two-day short refresh for more experienced pilots, and other specific courses. Among the lessons, because of the importance of physical efficiency in preventing hypoxia and decompression sickness and improving G tolerance, physical efficiency classes are given. Lessons include physical exercise, training, and nutrition; neck pain prevention has been recently added. At the end of the course pilots are provided with a CD containing all the lessons.

3. The message pilots are asked to bring home is that:

   a. Maintaining a healthy lifestyle and a good physical efficiency has several benefits: some of them are long-term benefits, such as reducing oxidative stress and aging-related damages, reducing cardiovascular risk, preventing metabolic disorders, improving brain work and reducing age-related cognitive impairment; some others are short- to medium-term benefits such as preventing injuries, improving resistance to fatigue, wellness, sleep quality and thermoregulation. Concerning flight activity, a good physical efficiency is a matter of safety.

4. A good training programme should be tailored to the age, sex, current and previous fitness level, and focused on the goals to be reached. Furthermore, a good training programme is progressive and regular with adequate periods of workout and recovery. Performance increases are achieved through increased training loads, which are tolerated only through interspersed periods of rest and recovery. Physical exercise is a stressor for the body; during the recovery phase, the body reacts in order to be prepared to bear the next stress. This is why recovery is even more important than the workout phase in improving strength, resistance and muscle mass. An inadequate training programme can lead to a maladapted response to excessive exercise without adequate rest.

5. Ideally, training is a combination of endurance and strength sessions. High-intensity interval training is a good way to combine these two types of training in the same workout.

   a. Endurance is beneficial in particular for the cardiovascular and respiratory system. Good endurance training for non-athletes consists of at least 40 minute-workout (running, swimming, cardio-fitness, cycling) three times a week. A simple way to check if you are doing well is to train within aerobic optimum range (65% – 85% of maximum heart rate). Pilots should do endurance training because efficient cardiovascular and respiratory systems are very important in preventing hypoxia and decompression sickness in flight but they should not exceed in performing it. This is because it has been shown that overly strenuous endurance training can reduce G resistance and delay recovery after G-LOC during centrifuge exposures.

b. Strength training increases muscle strength, improving both muscle fibre size and recruitment. It is very useful in fast jet pilots, who are required to perform anti-G straining manoeuvres, a very fast isometric contraction of large muscle groups, including the quadriceps, gluteus, and abdominals, in order to push blood to the brain during high +Gz loading to prevent G-LOC.

c. Both free weights and machine weights can help increase strength; other types of resistance, such as using resistance bands or body weight, also can help in increasing strength. Free weights enable performance of natural movements and are good for coordination and proprioception; at the same time a good technique is necessary due to the high injury risk and vertebral column stress. However, training on machine weights do not reproduce natural movements and do not improve coordination and proprioception but are easy to learn and at low injury risk and impact on back. The choice is based on personal preferences, physical fitness level, fitness goals, and access to equipment.

6. Nutrition training involves briefly explaining how energy is derived from metabolizing fats and carbohydrates, while the main role of proteins is building blocks of body tissues (anabolic function); we suggest pilots should choose complex carbohydrates and "good" fats before training in order to improve energy supply and proteins after training to build muscle mass and restore minor muscle injuries:

a. Supplement use is discussed because of the overuse of these substances, even in recreational sport, is unfortunately very common. Carbohydrates, proteins / amino acids, vitamins or minerals supplements can be useful only when diet cannot provide all these nutrients, in very high-intensity activity or in extreme environments; all conditions that are uncommon in non-professional sports. In the other cases supplementation is useless or even harmful. Mineral supplements can sometimes be useful before high-demanding flight performances in hot environment.

b. Nutrition is related to two flight hazards: dehydration and hypoglycemia. Dehydration occurs when free water loss exceeds free water intake, usually due to exercise, disease, or high environmental temperature. We suggest drinking often during the day and to drink before being thirsty; becoming thirsty is actually a late symptom. Urine colour is a reliable indicator of hydration status.

c. Hypoglycemia occurs when blood sugar decreases to below normal levels, resulting in a variety of symptoms, including mental impairment up to loss of consciousness. This can be very dangerous condition in normal situations and even more so during a flight. We suggest not to fly when they are starving, not to consume sweets and sugar drinks before flying, and not to eat excessive carbohydrates.

7. Since the beginning of "Aircrew Neck Pain Project," a section about prevention of neck pain has been introduced. This includes showing images of the vertebral column to explain its anatomical and functional features. In particular, the importance of physiological curvatures in order to absorb the load of the head-supported mass. Common mechanisms of damage of soft tissues muscle and ligaments are explained.

a. Concerning flight activity, we advise our pilots to not underestimate their neck pain to keep active flight status and we make them aware about short-term and long-term consequences of neglected lesions on their career and life.

b. Concerning neck pain management, both acute and chronic, we instruct pilots to consult physicians and physical therapists only, avoiding nonprofessional management and treatment. We explain that having a sufficient recovery between flights is very important. As we are well aware that in many cases pilots take anti-inflammatory and anaesthetic drugs without any prescription, we suggest that they pay attention to side effects of some drugs that could pose a risk in flight.

8. We instruct pilots to "THINK AS ATHLETES" and people surrounding them to "THINK AS AN ATHLETIC STAFF," suggesting that they take any conduct to improve readiness and efficiency and to take precautions about everything that could compromise the performance. With this in mind, we recommend pilots be careful about extra physical activity, in particular overloads and extreme sports and to let external gym instructors know about their professional activity, in order to avoid inappropriate exercise programmes. We recommend chiefs of the squadrons that both general and specific exercise programmes (at least 3 hours per week) are essential for the best result.

9. At present, according to the Italian Directive SMA-ORD 034 (last update in August 2016) aircrew have the chance to practice sport at work twice a week (for a total of 4 hours per week) and they must undergo to the annual assessment consisting of running, push-ups and crunches. Although during aero-physiological courses they receive directions about training requirements with regard to flight activity, they can choose work-out on their own.

F.2 OUTLINE OF THE FINNISH PREVENTIVE EDUCATION PROGRAMME

1. Anatomy
   a. Human anatomy in basic level
   b. Spine, neck and low back muscles and how they function
   c. Pain: acute, sub-acute, and types of pain
      1. After training
      2. After trauma
      3. Implications of flight planning
   d. Time for healing for skin, muscles, joints and bone

2. Sitting (posture)
   a. At home, work, driving, in cockpit
   b. How to position the chair? What kind of workplace is good?
   c. The importance of good ergonomic design

3. Head supported equipment
   a. Helmet, mask, and NVG fitting

4. Fitness
   a. Basic training in gym, how to avoid back and neck pain
   b. Training before flights

   c. Training for during flight or while waiting
   d. Training after flights
   e. Stretching at home

5. Nutrition
   a. Practice good nutrition
   b. Use of food / sport supplements
   c. Awareness of blood sugar and blood sugar test
   d. Avoid Atkins diet, Garbo diet
   e. Avoid energy drinks and other supplements that include Taurine
   f. Caffeine is allowed

6. Ergonomic training in cockpit
   a. Video simulated flight activity in the cockpit
   b. Review a video analysis of their performance and how it may affect pain generation
   c. Review how to reduce pain by altering posture and movement behaviour

7. Sleeping, work-rest
   a. Discuss how many hours of sleep are needed
   b. How to improve sleep during training
      1. Use a place conducive to good sleep use ear plugs if too loud
      2. Manage activity: avoid the tendency to do more than what you have to do; you don't have to "know everything or be everywhere"

8. Mental aspects
   a. Firstbeat testing
      1. Firstbeat (www.firstbeat.com) monitors heart rate and performs a heart rate variability analysis and is used to provide feedback on work and rest balance. During the test sensors are placed on the body during 3 days and nights. That test shows stress levels and sleep quality. The Finnish Air Force has monitored its pilots during last six years. The overall experience using Firstbeat (first used for four years in the civilian sector) has shown its value as an effective method to teach and motivate, including how to move and balance work and rest.
   b. Discuss how stressful pilots are
   c. Discuss those things which result in stress
   d. Understanding personal levels of stress
   e. Techniques to handle stress and work and home

F.3 OUTLINE OF THE PORTUGUESE PREVENTIVE EDUCATION PROGRAMME

1. Gz Forces

    a. A briefing is given on G forces with the purpose of making known the consequences of the acceleration exposure on the performance of crew. Factors that increase tolerance to Gz such as body position, particularly during manoeuvres, anaerobic training, anti-G equipment and AGSM are listed and explained. Likewise, factors that decrease tolerance to Gz such as hypoglycemia, alcohol consumption, fatigue, hypoxia, and obesity are explained. Portuguese pilots receive their centrifuge training in the Netherlands facility.

2. Work-Rest Cycle

    a. A briefing is given to make aircrew aware the dangers of fatigue. The potentiating factors, the main symptoms and the types of fatigue are discussed. The theme of circadian rhythms is developed. Adequate behaviours to avoid fatigue are explained (hours of sleep; type of meals; hydration; work-rest cycle; smoking and alcohol habits).

    b. The Commanders are conscious of this problem, but planning is very variable amongst aircraft types.

3. Nutrition

    a. There is a briefing about self-imposed stress (caffeine, self-medication, alcohol, tobacco, and nutrition). In each Unit there is a nutritionist responsible for preparing meal menus for military personnel.

4. Stress

    a. A briefing is given that aims to explain the influence of flight stress (noise, vibration, low humidity, extreme temperatures), physiological stress (thirst, hunger, sleep, fatigue, pain), and cognitive stress, and how they each affect performance.

5. NVGs

    a. This briefing is in addition to teaching how to use NVGs, pilots are alerted to the effect that increased equipment weight may have on performance and neck pain complaints. It reinforces the importance of muscle strengthening of specific muscle groups to protect against cervical injuries.

6. General Training Programmes for Aircrew

    a. The programme is oriented according to NATO Standard Agreement 3114.

7. Preventive Exercises

    a. In addition to awareness of the need to reinforce specific muscles, pamphlets are distributed with images and simple explanations of exercises that can be performed in order to warm up, strengthen and relax the cervical muscle chains and the shoulder girdle.

    b. Most pilots (especially fighter pilots) have developed their own training programmes which are intended to strengthen not only the cervical muscles but also all the muscle groups that are important in increasing the tolerance to G forces.

c. There are sports technicians in all military units whose role is to elaborate training programmes with specific objectives and to supervise military training.

d. Annually, all military personnel until the age of 50 have physical evaluations. When they are considered unfit, they are included in a training programme. The navigating personnel have specific physical tests where the strength of certain muscle groups is tested.

8. Controlled Helmet Fitting

   a. The helmet template is made and adjusted at the time of distribution; however, there is no periodic checking.

9. Ergonomics

   a. The F-16 pilots have a very high degree of satisfaction with regard to the ergonomics of the aircraft, namely in relation to the inclination of the seat, which is considered to provide a good weight distribution over the whole torso when under G loading. Whenever possible, the pilots try to adopt a position in the aircraft that allows them to support the body in the structure (seat, canopy) to withstand the increase of weight under G forces.

   b. The main problems detected, besides the issues already addressed, were the use of life jackets in the A – JET and the seat used by cabin operators in P3, C295 and EH101 in search and rescue missions.

10. Cervical and Lumbar Supports

   a. There is no cervical support. Lumbar support MFA 410 – 1 C is used by helicopter personnel and recommended for all other aircraft except for fighter jets.

F.4 OUTLINE OF THE BELGIAN PREVENTIVE EDUCATION PROGRAMME

1. Mental aspects
   a. Rest and recovery
      a. Sleep
         i. Sleep Physiology
            1. Organization sleep wake rhythm
            2. Organization night sleep
            3. Characteristics of night sleep
            4. Vigilance
            5. Signals of hypo-vigilance
            6. Effects of sleep deprivation
         ii. Management of sleep and vigilance
            1. Rules for good sleep hygiene
            2. Power naps

iii. Desynchronization Syndrome (Jet Lag)

1. Causes of Jet Lag
2. Influencing factors
3. Symptoms
4. Prevention and treatment

b. Recovery techniques

i. Relaxed breathing

ii. (In)direct muscle relaxation

iii. Relaxing mental imagery

b. Behaviour and Mental Fitness

a. Stress management

i. Psycho-education

1. Stress definition
2. Biology of stress
   a. General Adaption Syndrome (Selye)
   b. Positive vs. negative stress
3. Psychology of stress
4. Responses to stress
   a. Physiological
   b. Cognitive-behavioural
   c. Fight-Flight-Freeze
5. Stress factors
   a. Environmental factors
   b. Individual factors
6. Mental Health Continuum

ii. Recovery techniques

1. Relaxed breathing

iii. Biofeedback / heart coherence (to be determined)

b. Motivation

i. Psycho-education

1. Definition of motivation
2. Theories

3. Motivational determinants
4. Impact on motivation
5. How to motivate?

ii. Mental motivation techniques

1. Positive reinforcement
2. Mental Projection of Succeeding

c. Dynamization techniques

1. Energizing breathing
2. Energizing mental imagery
3. Mental Pre-activation
4. Psycho-physiologic dynamization

d. Regulation techniques

1. Reflex-correction signal
2. Determining the activation level

2. Nutrition and hydration

a. Nutrition

a. Energy

i. Energy in food
ii. Calculation energy requirement

b. Proteins

i. Classification of proteins
ii. Importance of proteins in the diet
iii. Proteins and vegetarianism

c. Carbohydrates

i. Classification of carbohydrates
ii. Importance of carbohydrates in the diet
iii. Sugar and health

d. Fats

i. Classification of fats
ii. Importance of fat in the diet
iii. Fat and health

e. Minerals
    i. Classification of minerals
    ii. Importance of minerals in the diet
f. Vitamins
    i. Classification of vitamins
    ii. Importance of vitamins in the diet

b. Sports nutrition
    i. Basic principles sports nutrition
    ii. Carbohydrates and endurance
    iii. Supplements in sport
c. Hydration
    i. Basic principles hydration
    ii. Dangers of dehydration
    iii. Types of beverages
d. War fighter nutrition
    i. Basic principles war fighter nutrition
e. Overweight and obesity
    i. Overweight and obesity prevalence
    ii. Overweight and obesity prevention

3. Physical Fitness
   a. Anatomy and biomechanics
      a. Cervical Spine
      b. Lumbar Spine
      c. Ligaments
      d. Muscles
   b. Risk factors
      a. Positions and Postures
      b. Sitting
      c. Standing
      d. Training
      e. Helmet and HMD (Helmet-Mounted Display)
      f. Rest and Recovery

- g. Personal Hygiene
- h. Psychosocial elements in injuries

c. Prevention programme
- a. Functional screening and assessment
- b. Content and follow-up
- c. Report
- d. Conclusions
- e. Re-train

d. Preventive training programme
- a. Introduction (instructions for use, why, …)
- b. Contents

e. Pre-flight exercises

f. Stabilisation
- a. Neck
- b. Trunk, legs, arms

g. Strength (strength endurance, hypertrophy, maximal strength)
- a. Neck
- b. Core Stability

h. Stretching
- a. Neck
- b. Trunk, legs, arms

i. Cardiovascular fitness (anaerobic capacity)

4. Medicine and Environment (Flight Surgeon, Canadian Medical Association)

a. Atmosphere

b. Respiratory and Cardiovascular System

c. Hypoxia

d. Changes in atmospheric pressure

e. Noise, vibration, nose, throat, ears

f. Hygiene

g. Spatial disorientation

h. Accelerations

i. Ejections

j. Air sickness

k. Decompression sickness

l. Thermal stress

m. Eye night vision

n. Airevac

o. Sleep-wake rhythm

p. Tropical Pathology

Annex G – FUNCTIONAL NECK CHECKS

G.1 FUNCTIONAL NECK CHECK FOR FAST JET AIRCREW

Aircrew returning to flying duties after neck injury or with recognised neck restrictions should have formal assessment of their capability in role. The assessment should be conducted by suitably qualified and experienced persons, e.g., Senior Operator/Instructor. The outcome of the assessment should be recorded within the aircrew flying records and on the Medical Information System. Aircrew should be reviewed after one month or ten hours of flying, whichever occurs first. The following activities serve as a checklist.

G.1.1 On the Ground

Should be dressed for role and capable of satisfactory completion of the following tasks:

a. Aircraft walk round including inspection of underside of fuselage.

b. Demonstrate technique for moving head whilst under G loading.

c. View all gauges, screens and avionics that are relevant to role.

d. Access all controls, avionics, and switching that are relevant to role.

e. Lookout check, from 7 o'clock through to 5 o'clock, through canopy.

   i. Must have harness secured as per normal flight.

   ii. With and without NVG.

G.1.2 When Flying

Should be dressed for role, in representative positions within the cockpit and capable of satisfactory completion of the following tasks:

a. Ability to keep sight of other aircraft whilst in formation.

b. Ability to conduct lookout in ‘check 6’ position.

c. Ability to conduct lookout in representative positions and postures whilst wearing NVG.

Fast Jet pilots should be advised to:

a. Fly non-combat sorties initially.

b. Progress through an offensive air combat sortie.

c. Complete a defensive air combat sortie prior to returning to full flying.

Follow-up consultation with the Flight Surgeon after one month or ten hours of flight.

G.2 FUNCTIONAL NECK CHECK FOR ROTARY/MULTI-ENGINE COCKPIT CREW AND REAR CREW

Aircrew returning to flying duties after neck injury or with recognised neck restrictions should have formal assessment of their capability in role. The assessment should be conducted by suitably qualified and experienced persons, e.g., Senior Operator/Instructor. The outcome of the assessment should be recorded within the aircrew flying records and on the Medical Information System. Aircrew should be reviewed after one month or ten hours of night flying, whichever occurs first. The following activities serve as a checklist.

G.2.1 Cockpit Crew

Should be dressed for role and capable of satisfactory completion of the following tasks:

a. Aircraft walk round including inspection of rotor head and underside of fuselage.

b. Lookout check, from 7 o'clock through to 5 o'clock, through chin windows and above.

   i. Must have harness secured as per normal flight.

   ii. With and without NVG.

c. View all gauges, screens, and avionics that are relevant to role.

d. Access all controls, avionics, and switching that are relevant to role.

e. Conduct rapid emergency egress from cockpit or cabin exits in accordance with aircraft egress drills.

G.2.2 Rear Crew

Should be dressed for role and capable of satisfactory completion of the following tasks (where applicable to role):

a. Monitoring aircraft separation (blades, tail and landing gear) from lateral obstructions and ground in the final approach configuration whilst wearing NVG.

b. Lookout in representative positions and postures whilst wearing NVG.

c. Monitoring and controlling the under slung load whilst wearing NVG.

d. Winch operation including recovery of persons or stores.

e. Fast rope dispatch and recovery.

f. Control and activation of crew served weapons.

g. Restraint of internal loads.

h. Data input and monitoring of required avionics whilst wearing NVG.

i. Follow-up consultation with the Flight Surgeon after one month or ten hours of night flight.

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14. Abstract

Aircrew neck pain has been shown to significantly degrade aircrew health and wellbeing, operational performance and mission effectiveness. A successful strategy to minimise aircrew neck pain requires the identification of possible aircrew neck pain risk factors, and the application of evidence-based solutions to mitigate these risks.

NATO HFM-RTG 252 Aircrew Neck Pain has developed evidence-based recommendations to minimise flying-related neck pain and optimise aircrew health and operational performance. These include:

- An enduring comprehensive physical conditioning and monitoring programme that reflects flying tasks and physical demands, promotes physical recovery between high-risk activities, with easy access to physical therapy to sustain performance and accelerate recovery after minor and chronic or pre-existing injuries and strains;
- Helmets and helmet-mounted equipment should be designed to minimise neck forces and be compatible with other body-worn equipment and cockpit structures; and
- Postures and movements most-associated with neck pain and injury should be identified, and minimised to the greatest extent possible.

Notwithstanding the physical demands imposed on military aviators and the inherent risk of neck pain, this report provides advice to aircrew, commanders, aviation medicine specialists, and health and fitness personnel for tangible ways to reduce flying-related neck pain and optimise flight performance and mission effectiveness.

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