



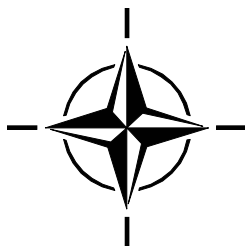
RTO TECHNICAL REPORT

TR-HFM-083

Review of National Work Programme on the Long Term Effects of Sustained High G on the Cervical Spine

(Analyse du programme de travail national :
les effets à long terme sur la colonne cervicale
d'un nombre de G élevé et prolongé)

This Report of the Task Group HFM-083 documents a review of national work programme concerning adverse effects on the cervical spine related to high sustained G in high performance aircraft and attack helicopters.



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Edited by:

Karin Harms-Ringdahl, PhD, RPT

The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- 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

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Review of National Work Programme on the Long Term Effects of Sustained High G on the Cervical Spine

(RTO-TR-HFM-083)

Executive Summary

Empirical evidence, as well as long term studies with radiographic techniques, suggests that flying high performance aircraft has an adverse effect on the cervical spine of aviators. The load an aviator's neck supports is also exacerbated by the increasing use of head supported devices. As such, the effects of acceleration, vibration and repeated jolt also increase the risk of cervical injury to the cervical spines of helicopter pilots and crew. Thus, the RTO-group HFM-083 was created to determine the extent of the effects due to long term exposures to sustained G levels and to develop mitigation recommendations. As causes, consequences and counteracting measures are multidimensional and complex, different nations have focused on diverse aspects of the problem. The contributions from seven national programmes are reported. These comprise Aircrew questionnaires, countermeasures, treatment, characterisation of the spinal pain beyond questionnaires, muscular activity (EMG), imaging (MRI), and modelling.

Recommendations for future work are provided. One of these is the creation of a common database of biomechanical analyses, methodologies, and human responses to apply to common areas of concern across the member nations. The database should comprise standardized data capture and management and linked to information about intrinsic factors and medical issues, ergonomic and equipment issues (helmets and seating), and modelling. Such a system could be used within NATO to facilitate evidence-based decisions (e.g., procurement, policy, training, interventions for injury) and help to identify future research requirements.

Analyse du programme de travail national : les effets à long terme sur la colonne cervicale d'un nombre de G élevé et prolongé

(RTO-TR-HFM-083)

Synthèse

L'évidence empirique ainsi que les études à long terme utilisant des techniques radiographiques font penser que le vol sur avion hautement performant a un effet défavorable sur la colonne cervicale des aviateurs. L'effort supporté par le cou d'un aviateur est aussi exacerbé par l'utilisation croissante des équipements de tête. De plus, les effets des accélérations, les vibrations, les secousses répétées augmentent le risque de blessures cervicales des pilotes d'hélicoptères et de l'équipage. Ainsi, le groupe RTO HFM-083 a été créé afin de déterminer l'ampleur des effets subis lors d'un nombre de G prolongé et de développer des recommandations pour l'atténuer. Pour cette raison, les conséquences et les mesures de neutralisation sont multidimensionnelles et complexes, différentes nations se sont focalisées sur les divers aspects du problème. Le rapport restitue les travaux de sept nations. Ces travaux comprennent les questionnaires équipages, les contre-mesures, le traitement, la caractérisation de la douleur à la colonne vertébrale au travers de questionnaires, d'activités musculaires (EMG), d'imageries (IRM), et de modélisations.

D'autres travaux sont recommandés pour l'avenir : la création d'une base de données commune d'analyses biomécaniques, de méthodologies et de réponses humaines à appliquer aux domaines concernés pour tous les états membres. La base de données devrait inclure la capture et la gestion de données normalisées : ces données donneraient une information sur les questions relatives aux facteurs intrinsèques et médicaux, à l'équipement et à l'ergonomie (casques et sièges), et à la modélisation. Utilisé par l'OTAN, un tel système permettrait de prendre des décisions de base évidentes (ex. : approvisionnement, politique, formation, intervention en cas de blessure, etc.) et serait une aide à l'identification des recherches à entreprendre dans l'avenir.

Chapter 1 – INTRODUCTION

by

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1.1 PROBLEM STATEMENT

1.1.1 Theme

Given the empirical evidence, as well as extended studies with radiographic techniques, that flying high performance aircraft can have an adverse effect on the cervical spine, there is an urgent need to study the long term consequences of repeated exposures to acceleration (G) and vibration in aviators.

1.1.2 Justification

In 1999 an AGARD Technology Watch Group published a report on the chronic effects of flying high performance aircraft on the spine (RTO-TR-4, 1999). A meta-analysis of the data included in this Technical Report indicated that repeated exposures to acceleration stress associated with flight increased the probability of developing degenerative changes at some levels of the spine. Furthermore, there is good evidence that acute musculoskeletal spine injuries with neurological deficits also occur when aircrew are exposed to high G onset rates. The risk of overloading the neck of aviators has also risen with the increased use of head supported devices. Factors such as increased mission duration and the expansion of some nations' aviator population to include small stature males and females have also affected overall injury risk. Deployment of vectored thrust aircraft in future will apply different G vectors on the neck than the ones now commonly experienced. It may well be that under these conditions adverse effects on the neck will dictate the use of lower G levels.

The 1999 Technical Report comprised a state of the art literature review of the occurrence of spinal injuries in aircrew. It was recommended to develop a follow-up prospective study with a common design conducted in multiple nations to differentiate between the physiological ageing of the spine and possible pathological findings due to long term G exposure. Thus, the RTO Group HFM-083 was created to discover the extent of adverse effects due to sustained G levels and to develop injury risk mitigation recommendations.

1.2 TOPICS TO BE COVERED

The work conducted under HFM-083 has centred on the effects on the cervical spine of flying high sustained G in high performance aircraft and attack helicopters. As causes, consequences and counteracting measures are multidimensional and complex, different nations have focused on diverse aspects of the problem. National priorities, group participation, and the financial support for the research in this area have varied substantially over the years, making it difficult to address the original goals of HFM-083. Therefore, it has not been possible to develop and conduct the prospective study as originally planned. As such, the work of the group has consisted of a technology watch and exchange of information

accomplished by use of the RTO website and a yearly meeting, held concurrently with the Aerospace Medical Association annual scientific meeting. This exchange has been quite valuable and has assisted the formation of collaborative work among the group's participants, e.g., use of the Belgian aircrew test battery of intrinsic factors related to neck pain used by the Netherlands. A summary of the relevant work conducted by seven national programs are reported in Chapters 2 – 8.

1.3 SUGGESTED FUTURE ACTIVITIES

While meeting yearly to share information on national programs has been of benefit to the participants, NATO RTA feels that there has been insufficient progress to justify continuation of HFM-083 beyond the writing of a final report. At the final meeting of the group, a revised plan of action for interested nations was discussed to propose a finite number (2 – 4) of specific targeted tasks that are achievable, worthwhile, and aligned with existing national programs. These tasks are designed to have national military relevance and have sufficient funding to sustain a three year effort. The following topics are presented as a starting point for the development of a new TOR document.

- **Aircrew neck pain / injury questionnaires:** Several nations have or are planning to distribute surveys to document the extent of neck pain and injuries. Developing and distributing standardized forms will increase statistical power and allow comparison of responses. Data would be obtained from rotary and fixed wing pilots and crewmembers. A common statistical methodology would be employed in order to issue a comprehensive summary of responses and recommendations.
- **Characterization of the spinal pain beyond questionnaires:** The prevalence of rotary wing neck pain/injury has been published in the aeromedical literature. But there are several factors influencing pain:
 - Issues associated with type of work performed within different areas of the aircraft affect injury risk. These include but are not limited to types of cockpit vs. cabin seating, equipment worn, level of physical effort involved with piloting vs. crew tasking, and the duration of these tasks.
 - Use of NVG and other head mounted displays.
 - While the occurrence of spinal pain has been established, the need exists to determine the operational relevance of the pain, i.e., does the magnitude and persistence of the pain interfere with mission goals?
- **Countermeasures:** Canvas member nations to determine what mitigation measures are under development. These include support devices/equipment, physical therapies, physical fitness regimens, aircrew screening and pass/fail criteria, and training. Based on this information, develop opportunities for collaboration.
- **Treatment:** If an injury occurs, determine what treatment to provide using an evidence-based approach and provide recommendations.
- **Electromyography (EMG):** Several nations are currently conducting studies using EMG. There is an opportunity to hold a mini-workshop to standardize methodology (techniques, measurements, data analysis, isometric vs. dynamic exertions) in order to more effectively compare and share datasets. The ultimate product would be the ability to increase statistical power of these studies and pool results.
- **Magnetic Resonance Imaging (MRI) studies:**
 - Define degeneration at intervertebral disc level;
 - Standardize nomenclature – define what constitutes bulging, hernia, etc;
 - Determine incidence of disturbances;

- Determine applicability of comparing results across platforms; and
- Determine relationship between degeneration and complaints, i.e., occurrence of asymptomatic signs without symptoms.
- **Modelling:** Capitalize on the various national efforts to model the spine for injury prediction in order to share data, compare methodologies and provide platforms for verification and validation of predictive algorithms. Determine what data already exists, identify knowledge gaps, and develop the means for sharing information.
- **Database of Biomechanical Analyses:**
 - A large number of diverse biomechanics studies have been conducted by member nations with potential benefit to military policy and in the development of procedures to mitigate injury risk. These range from kinesiology, design and integration of clothing and equipment, gait analyses, load carriage, finite element modelling of the spine, manual materials handling, work techniques (including posture and physical work-rest regimes etc.) and anthropometry. This has resulted in a large number of individual databases with limited access.
 - Results of these studies, when available, provide summary statistics and analyses rather than the data itself. An effort to coordinate and link access to this information within a single, standardized, secure, and robust system would greatly enhance the utility of extant and future research. It would promote greater information sharing across NATO, thereby achieving solutions to specific military needs in a timelier manner. A NATO standard would set a precedent for the international communities to follow. Such a system could then be used within NATO to facilitate evidence-based decisions (e.g., procurement, policy, training, interventions for injury, etc.) and help to identify future research requirements. Use of such data will enable military scientists and operational analysts within NATO to better understand the biomechanical limitations of the human body when considering those common military activities, such as supporting added head weight, manual materials handling, human load carriage, etc.
 - The approach would initially involve collating and examining those databases that are currently available to NATO members and then determine the feasibility of producing a ‘standardized’ database which is aligned with the intended applications for NATO forces.

Organization of a follow-on effort to HFM-083: Given the different national emphases, members of the new effort would be organized into dedicated subgroups with individual leads. For example, these subgroups could focus on:

- Intrinsic factors; medical issues;
- Ergonomics; equipment issues (helmets, seating); and
- Modelling.

An example of collaborative work that is already underway by Belgium and the Netherlands is the use of the Belgian aircrew test battery of intrinsic factors related to neck pain (e.g., reaction time, proprioception, etc.). If permission and access were granted, testing could be expanded to other countries. Possible avenues to facilitate collaboration include:

- Belgian pilots who perform basic training in France;
- The use of the Dutch centrifuge by Spanish pilots; and
- United States aircrew based in Germany use of the Dutch centrifuge in Soesterburg for training.

The goal of the Belgian protocol is to provide results to pilots and encourage them to alter their behaviour to conform to norms (established via testing protocol) to remain asymptomatic.

1.4 REFERENCE

- [1] Burton, R.R. Cervical Spinal Injury from Repeated Exposures to Sustained Acceleration. RTO-TR-4, 1999.

Chapter 2 – REVIEW OF THE BELGIAN AND THE NETHERLANDS NATIONAL WORK PROGRAMME ON THE LONG TERM EFFECTS OF SUSTAINED HIGH G ON THE CERVICAL SPINE

FUNCTIONAL ASSESSMENTS OF THE CERVICAL SPINE IN F-16 PILOTS – AN OVERVIEW

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2.1 INTRODUCTION

Neck pain in association with the dynamic work environment of the fighter pilot is a well-discussed issue. Spinal symptoms in these pilots were recognized as a serious aero medical problem. Often described contributing factors of neck pain in this population are head movements under high +Gz load, seat-back angle, forward bent posture, head worn equipment, the use of night vision goggles and numbers of flight hours [4, 5, 7]. This study was a collaboration of The Belgian Air Force and The Royal Netherlands Air Force; they both operate the F-16 Fighting Falcon. A battery of tests was developed for the functional assessment of the cervical spine, to provide a proper preventive training program for fighter pilots. This study was based on the injury prevention research by Van Mechelen et al. (Figure 2.1). According to the literature, lack of muscular force and endurance of the cervical spine could be one of the main risk factors causing neck pain [1, 2]. Although, other motor control impairments such as delayed reaction times, lack of range of motion, poor proprioception or muscular coordination and muscular imbalance could also play an important role in the occurrence of neck pain. Furthermore, psychosocial factors are also associated with neck pain. This report describes the methods used to identify the vulnerabilities within the functionality of the neck and presents the preliminary results.

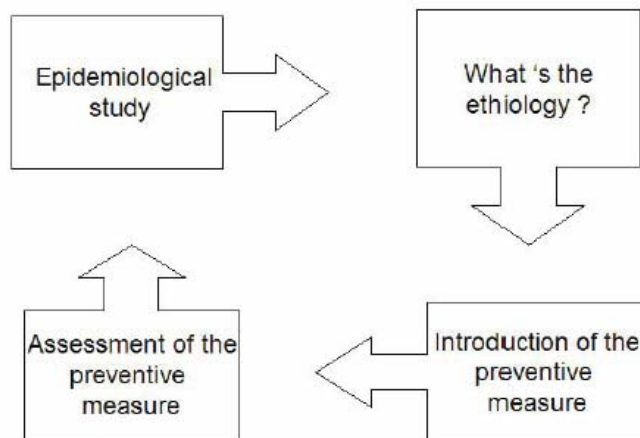


Figure 2.1: Four-Step Sequence of Injury Prevention Research.

2.2 METHODS

2.2.1 Subjects

Ninety male F-16 pilots (Table 2.1) of the Belgian Air Force and The Royal Netherlands Air Force participated voluntarily and gave informed consent. Anonymity was guaranteed by using a personal code; only the pilots owned the key to this code.

Table 2.1: Demographic Distribution of the F-16 Pilots

		Healthy pilots N=73		Neck pain pilots N=17	
		Average	C.I. (95%)	Average	C.I. (95%)
BMI		24.1	1.6	24.2	2.6
Years fighter pilot		9.5	5.4	9.7	5.2
		%		%	
Age	<30	47.1		41.1	
	30 – 39	47.1		56.2	
	40 – 49	5.9		2.7	
Flight	0 – 999	30.6		17.6	
hours	1000 – 1999	31.9		47.1	
	2000 – 2999	27.4		29.4	
	3000 – 4000	9.7		5.9	

The Belgian Defence and University of Ghent Ethical Research Committees approved the methods and measurements used. The tests were conducted in a random sequence. To avoid the influence of muscular fatigue on the other tests, muscular strength was always measured at the end of the evaluation. Besides the F-16 pilots, 22 male pilots in training of the Belgian Air Force participated. These pilots had less than 140 flight hours in low G aircrafts and experienced no neck pain.

2.2.2 Questionnaire

The questionnaire was divided into two parts: a general and a pilot specific part. The general part, based on the Dutch Musculoskeletal Questionnaire, was composed of questions concerning personal information, health, work situation, leisure activities, neck pain and the Neck Disability Index (NDI) [6, 8]. The NDI measured the self-rated disability during all day activities due to neck pain. The pilot specific part contained questions about flight experience, preventive measures and flight related causes of neck pain. Neck pain was defined as pain in the head and neck region, shades in a drawing of the head, neck and shoulder area [3].

2.2.3 Cervical Range of Motion

The cervical range of motion (CROM) was measured with the three-dimensional motion analyzer Zebris CMS20, WinSpine version 1.79 (Zebris Medizintechnik GmbH). The maximal CROM was measured for flexion – extension, right – left rotation and right – left lateroflexion. Each measurement consisted of three repetitions of each movement.

2.2.4 Proprioception

The proprioception was measured using the same equipment as the CROM, Windata version 2.20 (Zebris Medizintechnik GmbH). The starting position was the neutral position of his neck as defined by the pilot. The test consisted of two parts, first to return to their own neutral position after a sub maximum range cervical flexion-extension and right and left rotation, and second to return to a defined position (30° right or left rotation). For the first part the reposition error was calculated in the sagittal, frontal and horizontal planes, as a mean of 10 repetitions. For the second part the reposition error was calculated in the horizontal plane for right and left rotation, as a mean of 5 repetitions in each direction.

2.2.5 Reaction Time

A device called “Cervical Beamer” was developed to measure reaction time. The simple reaction time (i.e. 1 stimulus with 1 possible response) and the choice reaction time (i.e. 14 different stimuli with each 1 response) were measured. The reaction time was divided into decision time and movement time.

2.2.6 Muscular Strength of the Cervical Spine

The maximum isometric strength was measured with the David F-140 (David Back Clinic). The isometric strength tests were done in four directions: flexion, extension, right and left lateroflexion. Three maximum voluntary contractions were executed in each direction. The peak value (Nm) was registered; MVC was defined as the highest of the three peak values.

2.2.7 MRI

Candidates underwent MRI – evaluation of the cervical spine in supine position (Philips 0.5 T machine, no paramagnetic contrast material). Sagittal T1 and T2 weighted images were obtained and, in case of disc disorders, also axial T2 weighted images of the involved disc space. Discriminators of disorders were: degenerative changes in the intervertebral disc/discopathy in cervical spine, presence of osteophytes/osteophytic spurring, presence of osteophyte’s posterior in the spinal canal. Furthermore the cross-sectional area of the longus colli muscle, the longus capitis muscle, the sternocleidomastoid muscle, the rectus capitis posterior major muscle, trapezius muscle and the multifidus muscle was measured.

2.2.8 Statistics

Statistical analyses were performed with SPSS 12.0 software package (SPSS Inc., Chicago, IL) for windows. Differences between groups were calculated by cross-tabulations, a one-way-ANOVA, an independent sample's *t*-test or a Mann-Whitney *U* test (if normal data distribution was not obtained). Mean differences with 95% CI were given as descriptive statistics. In all tests, $p < 0.05$ was considered statistically significant. Pilots were divided in two groups: a neck pain group and a healthy group. Results of the healthy group were compared with the results of the pilots in training.

2.3 PRELIMINARY RESULTS

Year-prevalence of neck pain in F-16 pilots was 18.9%. High force demands, often sitting for a long time, often holding the neck in a forward bent posture and being physical tired at the end of the day; this were all physical work related factors which were significant pronounced in the neck pain group. Besides the physical factors the neck pain group reported significant more psychosocial factors as being mentally tired at the end of the day and being annoyed by others at the workplace. A sudden movement caused almost half of the pilot's neck pain and three fourths of the pilots with neck pain reported that their complaints were caused by the flight. Only a minority of the pilots who reported neck pain did consulted a physician.

Pilots experiencing neck pain had a less large range of motion in the sagittal and horizontal plan. No significant differences were observed between pilots with and without neck pain with regards to the reaction time, proprioception and maximal isometric strength.

Compared to the pilots in training the F-16 pilots of the healthy group had a significant better movement time and this in both cervical beamer tests. The MVC ratio flexion/extension was significant higher in the pilots in training. Though the flexion muscles were not significant lower in F-16 pilots neither were the extension muscles significant stronger than the pilots in training.

2.4 CONCLUSION

Prevalence was significant lower than a decade ago. The aetiology of neck pain is a complicated and a multifaceted problem. As in other populations, neck pain in F-16 pilots is a combination of different functional dysfunctions.

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2.6 FUTURE DIRECTION OF WORK PROGRAMME

- Analyzing MRI;
- Larger control group;
- Comparison fixed wing and helicopter crew;
- Assessment of deep neck flexors;
- Looking at movement strategies;
- Preventative programs based on individual values vs. normal values; and
- Collecting and analyzing values of prospective pilots.



Chapter 3 – REVIEW OF THE CANADIAN NATIONAL WORK PROGRAMME ON THE LONG TERM EFFECTS OF SUSTAINED HIGH G ON THE CERVICAL SPINE

DRDC RESEARCH EFFORTS ON NECK PAIN AND NECK PROTECTION

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3.1 BACKGROUND

Neck pain and neck injury, often sufficient to result in the permanent loss of flight status, has become a significant problem in Canadian Forces aircrew operating the CH146 Griffon tactical helicopter. The cockpit design of the aircraft imposes awkward head and neck positions and movements, and the use of night vision goggles (NVGs) is thought to exacerbate neck stress and injury. According to a recent survey more than 80% of CH146 Griffon pilots and flight engineers complained of neck pain associated with flight.

3.2 ONGOING WORK PROGRAMME

The Canadian research and development effort has focused on four areas:

- Developing statistical models to identify those factors that have a substantive contribution to the risk of developing neck pain and tissues damage. Using a logistic regression modeling approach the primary risk factors for the development of neck pain in CF and US Army aircrew have been identified as **total number of hours of NVG use and average number of NVG hours per mission**.
- Identifying the precise location of the stress and tissue strain imposed on the structures of the neck as a result of operational use of night vision equipment. In order to understand the mechanisms involved in the pain and tissue damage, a combined discrete-element and finite element model is being developed to calculate the interaction between dynamic loading and the constitutive properties of the cervical structures, the distribution of normal and shearing stresses and strains, and the subsequent genetic/biochemical changes in the cellular and extracellular materials.
- Developing a set of recommendations to operational procedures to reduce the total loading on the neck structures. Suggestions have been forwarded to the operational units regarding the proper placement of counter-weights and the need to maximize the amount of neck rest before, during, and following missions.
- Developing an aircrew controllable neck protection device to reduce the loading on the cervical structures due to increased helmet mounted mass, and dynamic head movements. A controllable system is being developed, based on electro-active material technology that will allow aircrew to

adjust in real-time the degree of neck and head support. The aim of the device is to minimize the total loading imposed by both the mass of the helmet and the subsequent neck muscle activation throughout the mission, but still allow maximum head mobility when required.

Future efforts will continue to focus on the development of biomechanical models, the development and flight testing of more advanced neck support technologies, and development of methods to minimize the impact of vibration forces on the neck. Work may also be undertaken to investigate neck problems in other aircraft and the efficacy of exercise and neck strength training to mitigate neck problems.

3.3 FUTURE DIRECTIONS OF WORK PROGRAMME

Future efforts will continue to focus on the development of biomechanical models, the development and flight testing of more advanced neck support technologies, and development of methods to minimize the impact of vibration forces on the neck. Work may also be undertaken to investigate neck problems in other aircraft and the efficacy of exercise and neck strength training to mitigate neck problems.

Chapter 4 – REVIEW OF THE GERMAN NATIONAL WORK PROGRAMME ON THE LONG TERM EFFECTS OF SUSTAINED HIGH G ON THE CERVICAL SPINE

by

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4.1 INTRODUCTION

The German Air Force Institute for Aviation Medicine (GAFIAM; German abbreviation: FMI) located at Fürstenfeldbruck is the **central** institute of the German armed forces (hereafter called *Bundeswehr*) for the relevant assessment and care of **all** pilots and aircrew members of **all** Services (Army, Air Force and Navy). In 1991, the establishment of the Orthopaedics/Traumatology Department was initiated along with specialized diagnostics and assessment of flying personnel was initiated.

In 1994, the Orthopaedics/Traumatology Department was permanently established at this institute (NB: in 2002, this department was expanded by the integration of the formerly separate Anthropometry Department).

The **Orthopaedics/Traumatology/Anthropometry** Department is in charge of assessing and giving expert opinions on the **total locomotor system** of the pilots, of the permanent and non-permanent aircrew members as well as of the applicants for the flying service of the Bundeswehr.

My department is supported by the interdepartmental radiology department of the FMI (digital radiography and MRT by Siemens mfrs.).

4.2 BRIEF DESCRIPTION OF ONGOING PROJECTS

A central mission of the aviation medical Orthopaedics/Traumatology/Anthropometry is the prevention and protection of pilots/WSOs (weapon system officers) from serious or even fatal injuries during ejector seat use as well as from acute or chronic consequences of flight operations.

4.2.1 Permanent Projects

Currently, the following three projects on this topic are underway:

- Validation of **anthropometric** data for military aircraft (poster presented at AsMA 2007 in New Orleans);
- Keeping and maintaining up-to-date **accident-related statistics** (since 1974; last update: 10/2007; presentation given at AsMA 2003 in San Antonio and poster presented at AsMA 2005 in Kansas City); and

- Validation of (first- time) **pre-flying orthopaedic examination** and radiology-based **selection procedures** as part of giving aviation medical expert opinions (presentation given at AsMA 2004 in Anchorage).

These are permanent projects.

Interim results were presented at the above-mentioned AMA meetings.

4.2.2 Inter-Vertebral Disc Lesions

A completed project is the assessment of the incidence rate of inter-vertebral disc lesions in Bundeswehr pilots.

The results were published under the title: **“Prevalence of Cervical and Lumbar Disc Disorders in Pilots of the German Armed Forces”** (presentation given at 1999 Aerospace Medical Association (AsMA) scientific meeting in Detroit).

This paper examined and evaluated **all** active aircraft pilots and WSOs (of the German Army, Air Force and Navy) examined at the GAFIAM in Fürstenfeldbruck in the period 08/1994 thru 12/1998.

The results were somewhat surprising: 9.9% of all helicopter, “only” **6.6%** of all Jet pilots/WSOs and 6.6% of all transport aircraft pilots of the Bundeswehr suffer from inter-vertebral-disc-induced lesions of the spine.

The control group (including no pilots) consisting of air traffic control personnel from eleven different Army Aviation Regiments) showed a higher incidence rate.

With 13%, the incidence rate of inter-vertebral-disc-induced lesions of the spine was highest.

I also studied the distribution of incidence of inter-vertebral-disc-induced lesions of the cervical and lumbar spine.

I also found a surprising result in this field of study: for all pilot groups studied (Jet, Hel, Transport aircraft, also among the control group) the proportion was 1:3 (cervical:lumbar).

I will not address any other results here.

4.2.2.1 Clinical Implications

These results resulted in the following consequences for the examination process at the FMI: We at first changed our radiological diagnostic equipment for pilot selection by replacing the CT (by Siemens mfrs.) by an **MRT** (“Harmony” also by Siemens mfrs.).

X-Ray examination of the spine as a spinal screening procedure was abandoned.

Since 01 Jan 2000, each aviation medical spinal screening conducted by us includes an MRT of the **total** spine (covering 2 separate parts: cervical and thoraco-lumbar spine).

Only in case of a justified medical indication will our examination also include digital radiography.

Another consequence was that this screening is applied to **all** applicants for the Bundeswehr flying service, i.e. also to future helicopter and transport aircraft pilots.

Each year, approx. 700 – 800 applicants will undergo MRT examinations of the spine at the GAFIAM.

Out of these 700 – 800 applicants, approx. 100 will subsequently be allowed to undergo flying training within the entire Bundeswehr (approximately 30 for HPFA).

These MRT examinations will then form the basis for **comparative** examinations (e.g. MRT checks of the total spine or separate sections thereof after 10 years of flying duty or after 1,000 flying hours).

4.2.3 Pilot Examinations

Another project resulted from the introduction of new and advanced aircraft into the Bundeswehr (the Euro-Fighter 2000 Jet aircraft, the NH90 Transport Helicopter, the TIGER attack helicopter and the A400M transport aircraft). Since 12 Oct 2004, we have been conducting the following examinations: F4-F PHANTOM II and Pa 200 TORNADO pilots who want to or who are earmarked for retraining for Euro-Fighter 2000 aircraft will undergo an „extra examination” at GAFIAM.

This examination encompasses a specialist orthopaedic examination, the anthropometric measurement (of 16 different body parts/areas) as well as an MRT screening of the total spine.

This examination for the Euro-Fighter 2000 aircraft (a single-seat aircraft) is complemented by an MRT examination of the skull and a cardiological examination.

A similar examination is done for BELL UH-1D pilots who are earmarked for retraining for the NH 90 as well as for Bo-105 pilots earmarked for retraining for the TIGER attack helicopter.

No examination is planned for retraining for the A400M aircraft.

A control MRT examination of the cervical (lumbar) spinal regions is planned to be performed after 5 years of flying these new aircraft.

Unfortunately, industry is causing us some relevant problems.

Due to considerable aircraft delivery delays (EURO-FIGHTER 2000 and TIGER attack helicopter; the NH90 helicopter has not yet been fielded) and the resulting few flight hours so far on these new aircraft types, an examination taking place in 5 years will not be very useful.

So far, 87 aircraft pilots (mainly F-4F PHANTOM II pilots, fewer Pa 200 TORNADO pilots) have been examined in accordance with the above procedure.

The interim results are as follows:

- 2 pilots out of 87 did not meet the anthropometric requirements of the aircraft type they were assigned to (leg length < 100 cm);
- 6 pilots out of 87 were not retrained for EURO-FIGHTER 2000 aircraft due to spinal lesions (5 cases: cervical spine, 1 case: lumbar spine); and
- 2 pilots out of 87 were not retrained for EURO-FIGHTER 2000 aircraft due to neurological findings (1 case: brain tumor, 1 case: cervical syringomyelia) (presentation given to the Supreme Commander of the German Air Force in Köln-Wahn on 21 Nov 2007).

From a cardiological point of view, all of the candidates were fit for retraining for the EURO-FIGHTER 2000 aircraft.

The average age of the pilots was 35.5 years, and their average number of flight hours was 1685.

In **66.1 %** of all pilots whom I examined, I found degenerative lesions of the **cervical spine**, in 49.1% of the thoracic spine and in 62.5% of the lumbar spine.

Interim evaluations of helicopter pilots are planned for the near future.

Relevant studies are not yet complete (they will be complete probably by the end of 2009).

Another project underway at GAFIAM is the determination of performance capacity of the neck and torso muscles of Bundeswehr aircraft pilot applicants.

The FPZ strength measurement equipment (by SCHNELL mfrs.), featuring 6 individual devices: 2 devices for the cervical spine, 4 devices for the lumbar spine and a central evaluation unit, is used to determine in 2 tests (Test 1: maximum strength test, the so-called "5 sec-Test"; Test 2: isometric strength endurance test, 100 sec 60% of maximum strength expressed in Nm and in Nm/kg) the muscular performance of the cervical spine (flexion/extension, lateral flexion, left/right, rotation left /right) and of the torso (flexion/extension, lateral flexion, left/right, rotation left/right) (Poster presented at the 2006 AsMA meeting in Orlando).

Since 2004, a data base has been established and is being maintained at GAFIAM (male applicants, female applicants, Jet pilots, Hel pilots, "personnel suffering from spinal lesions").

4.3 FUTURE PROJECTS

The following further projects in my department are planned:

- Determining the factual load on the **cervical spine** in the cockpit (head position and G-load).
- Developing special training programs for Jet, Hel pilots.
- Developing a computer-assisted spinal program (model) to enable us to better explain loads and/or injury risks.
- Answering the question as to the qualitative and quantitative role of heavy pilot helmets in degenerative processes of the **cervical spine**.

4.4 SUMMARY (INCLUDING SOME PERSONAL COMMENTS)

All of the above research and/or projects were/are carried out by myself and/or were/are compiled by me.

Since 1999, I have been presenting my projects and results on a regular basis at national and international meetings (AsMA, IMASSA, RTO). Unfortunately, my department has been understaffed since 06/2006 (only 50% of the allowable staff is available). Thus, I can dedicate only about 10% of my time to scientific work.

I strongly advocate (first-time) pre-flying orthopaedic screening, including **MRT** diagnostics of the **whole** spine of candidates who are fit for piloting military aircraft.

The **selection** of fit candidates on the hand is as important as continuous **orthopaedic specialist care** for active pilots and active aircrew on the other.

We have known for quite a while now that the „mechanical” performance limits of pilots and the introduction of High-Performance Fighter Aircraft have already been reached or will even be **exceeded** (max. G_z , G-onset, integrated helmet systems, heavy pilot suits, bailout for ejection seat use ...).

Pilots must be aware of their limits (i.e., awareness), and we in our capacity as flight surgeons and specialists must protect them (i.e., selection, prevention). Pilots must be active themselves (i.e., personal prevention).

I very frankly say this because the papers, projects and results of the Working Group hardly ever convinced me.

Aviation medical MRT diagnostics is still dealt with controversially by numerous NATO countries (maybe except for Finland and Spain).

Numerous countries do **not** want to apply any orthopaedic and MRT screening while selecting their HPFA pilots (stating the excessive costs (!) of an MRT as a main reason).

There are **no** orthopaedic specialists among the flight surgeons in NATO countries (the main reason being stated: orthopaedists are not necessary. If problems occur, specialists at hospitals or universities will be consulted). What is an MRT good for, if there is no combined orthopaedic specialist / flight surgeon is available to read it?

I am also **not** convinced by the current concept to reduce spinal loads and/or damage exclusively to the cervical region of the spine.

As an orthopaedic specialist I look at the spine as a **whole organ** in itself (with its separate cervical, thoracic and lumbar regions and the sensitive juncture between the cranio-/atlanto-axial juncture as well as the juncture between the lumbar spine/sacrum/pelvis).

Relevant to this, see my presentation to AsMA 1999.

When considering another established fact in aviation medicine, namely that approx. 90% of all fractures suffered by all pilots/WSOs following a successful and survived use of the ejection seat occur in the middle and lower portions of the thoracic spine and in the upper portion of the lumbar spine, and thus **only 10%** occur in the **cervical** spine, I am even less convinced by the current concept geared toward reducing the loads on the cervical spine.

In my capacity as an orthopaedic specialist *and* flight surgeon I rate neither the former approach nor the former results as scientifically satisfactory.

Even though these annotations are my personal opinion, they are based on my own extensive research efforts.

I am aware that my statements are not of a final, but rather of an interim character.

I will be able to present further results in 2009/2010, when our transition from X-Ray diagnostics to MRT diagnostics, which occurred on 01 Jan 2000, will hopefully have proven effective.



Chapter 5 – REVIEW OF THE SWEDISH NATIONAL WORK PROGRAMME ON THE LONG TERM EFFECTS OF SUSTAINED HIGH G ON THE CERVICAL SPINE

by

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5.1 BACKGROUND FOR CURRENT NATIONAL PROGRAMME

Neck pain among military pilots is a clinical and challenging problem in modern air forces. While pilots on flying duty represent a relatively homogenous group with similar selection procedures and training, a main question is why some pilots suffering episodes of neck pain related to flying while others do not. Research in various populations shows neck-muscle motor dysfunction in individuals with neck pain disorders, such as altered neck motor activity and changed electromyographic patterns due to fatiguing tasks. In the literature, evidence for early prevention and exercise treatment is relatively sparse. In fighters flying fast jet aircraft, neck muscular strength conditioning has been suggested, although such strategy may not be very helpful among individuals that already suffer from pain episodes. To date, however, few address the utility of exercise therapy as prevention for neck pain in helicopter pilots. Further research in this field may help to meet the further need for validated screening assessments and evidence-based exercise regimens in air forces, also including fast jet aircraft pilots, where Night Vision Goggles (NVG) dramatically increase the load on neck structures.

5.2 SPECIFIC RESEARCH TOPICS UNDER INVESTIGATION

The aims of our national program the past years has largely been to estimate potential risk factors involved in helicopter pilots' neck pain, to explore neck motor function in fighters as well as in helicopter pilots in various condition of neck pain and to examine the effect of an early neck/shoulder exercise intervention for neck pain in pilots. This has also been preceded by methodological and ergonomically investigations.

5.3 BRIEF DESCRIPTION OF STUDIES AND RESULTS

Published studies in the open literature the past three years are here listed for further/specific information:

Ang B, Harms-Ringdahl K. Neck pain and related disability in helicopter pilots: A survey of prevalence and risk factors. *Aviat Space Environ Med.* 2006 Jul;77(7):713-9.

Ang B, Linder J, Harms-Ringdahl K. Neck strength and myoelectric fatigue in fighter and helicopter pilots with a history of neck pain. *Aviat Space Environ Med.* 2005 Apr;76(4):375-80.

Ang B. Impaired Neck Motor Function and Pronounced Pain-Related Fear in Helicopter Pilots with Neck Pain – A Clinical Approach. *J Electromyogr Kinesiol* 2007; doi:10.1016/j.jelekin.2007.01.002.

Submitted: Ang B, Monnier A and Harms-Ringdahl K. Neck/Shoulder Exercise for Neck Pain in Air Force Helicopter Pilots – A Randomized Controlled Trial.

Short conclusion: The supervised neck/shoulder exercise regimen improved neck motor function to some extent and had a positive early preventive effect over a 12-month period in reducing the occurrence of neck pain in air force pilots.

An Academic Thesis, Neck Pain in Air Force Pilots – On Risk Factors, Neck Motor Function and an Exercise Intervention (by Björn Äng 1997), covering the above papers.

Thuresson M, Ang B, Linder J, Harms-Ringdahl K. Intra-rater reliability of electromyographic recordings and subjective evaluation of neck muscle fatigue among helicopter pilots. *J Electromyogr Kinesiol* 2005 Jun;15(3):323-31.

Thuresson M, Äng B, Linder J, Harms-Ringdahl K. Neck muscle activity in helicopter pilots: effect of position and helmet-mounted equipment. *Aviat Space Environ Med* 2003;74:527-532.

Thuresson M, Ang B, Linder J, Harms-Ringdahl K.. Mechanical load and EMG activity in the neck induced by different head-worn equipment and neck postures. *Int J Industr Ergonom* 2005;35:13-8.

An Academic Thesis, On neck load among helicopter pilots : Effects of head worn equipment, whole body vibration and neck position (by Marcus Thuresson, 1996), covering the above three articles and further data on influence on EMG from vibration.

Short Conclusion: Electromyography (EMG) using surface electrodes over neck muscles could be measured in a reliable way. This was also the case with ratings of perceived exertion during a neck muscle endurance test. In a laboratory setting, forward flexed neck positions and neck rotation increased muscular activity levels significantly. There was also an increase when adding NVG to the helmet, while a counter weight compared to NVG only slightly decreased the levels. However, a substantial increase in magnitude of the induced neck flexing load moment was entailed with only a comparatively low increase in neck muscle activity levels, especially when related to a maximum muscular strength test. Thus, this must be considered when using EMG amplitude as a measure of neck muscle load during missions with and without NVG and different ergonomic interventions.

5.4 UNCLASSIFIED REPORTS/PUBLICATIONS/PRESENTATIONS AVAILABLE FOR DISTRIBUTION

See above – In addition a book has been written with the intention to create an informative toolbox for pilots concerning information about anatomy, physiology, pain related injuries, perceived health and how to prepare physically and mentally for missions. The book has been distributed to all Swedish Air Force pilots, and an English version is for sale (“Fit to Win”, Eds. Harms-Ringdahl K, Spångberg C, Ingemansson-Thoor. Swedish Air Force, Aero medical Centre, Stockholm, 2004, ISBN 91-631-4294-5).

5.5 FUTURE DIRECTION OF WORK PROGRAMME

Planned research activities over the next 12 months *dependent on further financial founding:*

- To initiate investigation of potential causality between altered neck-muscle motor function during pain-free episodes and future episodes of neck pain.

- Initiation of in vivo helicopter flight investigation of the relevance of neck muscle electromyographic response and perceived fatigue to in-flight neck pain while wearing various head-worn-equipment.
- To study an exercise intervention tailored for fighter pilots that by on large includes requirements for accuracy of movement control before adopting strengthening exercises.
- Hopefully, to initiate an international collaboration project that aim to:
 - 1) Standardize/develop measuring protocols and questionnaires for further reliable and adequate data sampling;
 - 2) From here, initiate an international database-program; and
 - 3) Collect and thoroughly analyze knowledge to further develop management guidelines for the prevention and rehabilitation of neck pain in air force pilots.

5.5.1 Work in Progress

The introduction of NVG into service use in fast jet-aircraft, such as JAS 39 Gripen, highlights the possibility of injuries or pain incidents being caused by the increase in helmet weight and adverse alteration of the helmet/head-worn equipment Centre of Mass (CoM). Therefore, a project have been initiated that aim to evaluate neck and shoulder muscle work load and fatigue using the NVG equipment in various g-profiles simulated in a modern dynamic flight simulator. In order to isolate the potential increased/changed muscle activity induced by the NVG equipment, a comparable test-design of 2 * 2.5 hour sessions are performed for each pilot (n = 6): one session is performed with NVG equipment and one session are performed without the equipment (with the ordinary helmet). The test program includes a static phase of 60 min and a dynamic phase of 90 min with standardized g-profiles including various g-levels and g-onset rates.

A “pilot” study that aim to study an exercise intervention tailored for fighter pilots that includes requirements for accuracy of movement control before adopting strengthening exercises.



Chapter 6 – REVIEW OF THE UNITED KINGDOM NATIONAL WORK PROGRAMME ON THE LONG TERM EFFECTS OF SUSTAINED HIGH G ON THE CERVICAL SPINE

by

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6.1 BACKGROUND FOR CURRENT NATIONAL PROGRAMME

Previous research has shown a similar prevalence of flight-related neck pain, determined from postal questionnaires, in fast-jet (40%) and rotary-wing aircrew (38%). The causes of neck pain, however, appear to differ and whereas fast-jet aircrew attributed neck pain to sustained high +Gz (>4Gz; 74%), rotary-wing aircrew associated their neck pain with wearing Night Vision Goggles (NVGs) (64%) (Wallis *et al.*, 2000, *Aviat Space Environ Med*, 171, P317). These findings indicate that rotary-wing aircrew are at equal risk of neck pain, but that the causes might differ. Furthermore, in a later, unpublished survey of rotary-wing air loadmasters (ALMs), perceived contributory factors for spinal pain reported by ALMs included equipment (e.g., NVGs and the flying helmet), posture and the type of tasks performed. These epidemiological findings led to a field investigation examining the physiological stress placed on the neck muscles under different head load conditions and in response to the tasks that Chinook ALMs perform (Greeves *et al.*, 2003, AVT-/RSM-012). Increased muscle activity was observed under heavier head loading conditions, depending upon the type of the tasks performed. Likewise, under controlled G exposure in a centrifuge, neck muscle activity was shown to increase when heavier head loads were worn (Wickes and Greeves, 2005, *Aviat Space Environ Med*, 76, P217). There is, therefore, growing evidence that the environment characteristics, equipment and role-specific tasks of aircrew increase the loads applied to the neck musculature, probably contributing to the high risk of flight-related neck pain reported on different platforms.

Strength training is a common intervention for the management of neck pain. Indeed, the aircrew environment itself may provide a training stimulus, particularly in response to G exposure, but other preventative strategies need to be explored. For example, the Ministry of Defence (MOD) is currently planning to introduce a lighter weight helmet, replacing current in-service helmets that are not only heavy, but use older technology. There is a priority, in particular, to reduce mass whilst meeting the new impact standards (Defence Standards 05102; 2006).

The objectives of the current work program were, therefore, to establish the prevalence and causative factors of neck pain in aircrew operating on both fast-jet and rotary-wing aircraft; to examine the effects of G exposure on neck muscle function in fast-jet aircrew; and, to evaluate the response of the neck musculature to different helmet mass properties.

6.2 SPECIFIC RESEARCH TOPICS UNDER INVESTIGATION

- The response of the neck musculature to environmental characteristics (G and whole body vibration) and different helmet mass properties;
- The effects of fast-jet training on neck muscle function and symptoms of neck pain in student aircrew; and
- The effect of Advanced Flying Training on cervical bone mineral density in student aircrew.

6.3 BRIEF DESCRIPTION OF STUDIES AND RESULTS

This research is funded by the Ministry of Defence Applied Research Program.

6.3.1 Work Completed

6.3.1.1 Study 1 – Prevalence and Associated Risk Factors of Flight-Related Neck Pain

6.3.1.1.1 Introduction and Aims

Few studies have examined neck pain in rotary-wing aircrew, particularly in rotary-wing ALMs. High G and heavy head-borne mass have been attributed to neck pain, although causative factors have not been fully explored. The aim of this research was to investigate the occupational prevalence of flight-related neck pain in Royal Air Force (RAF) fast-jet, rotary-wing front aircrew and ALMs; to identify associated factors of neck pain; and examine treatment patterns.

6.3.1.1.2 Methods

A cross-sectional questionnaire survey was designed for this study based on previously validated survey methods. Each subject was fully briefed on the purpose of the study and gave written informed consent before participating. The survey was divided into 2 sections:

- i) Lifestyle and musculoskeletal disorders; and
- ii) Aircrew characteristics.

The first section of the survey was designed to obtain demographic information. Subjects were required to self-report height, body mass and lifestyle habits. Body Mass Index was calculated for all subjects. Well-being scores for home and work were recorded on a 6-point scale over 12 categories for both work and home life. The second section characterised flying history, documenting the role of the subject, total flying hours, and NVG use. Information collected on neck pain included occupational prevalence (i.e., neck pain occurring over the course of their flying career); perceived causative factors; duration and severity of neck pain; and medical interventions.

Personnel from seven RAF stations were selected to undertake the survey, including both fast-jet and rotary-wing aircrew on training and operational units. Subjects were briefed in groups at their respective stations and were asked to complete the questionnaire. The aircrew were subdivided into three groups: fast-jet aircrew (FJ); rotary-wing front aircrew (RW) and rotary-wing ALMs.

6.3.1.1.3 Results

The questionnaire was completed by 417 aircrew, comprising 144 fast-jet aircrew, 188 rotary-wing front aircrew and 85 ALMs. Due to the small number female aircrew, statistical analysis was performed on data from the male population, reducing the sample size to 410.

Occupational Prevalence

- Sixty six percent of all aircrew reported flight-related neck pain at some point during their flying career. Neck pain was higher in FJ (69.9%) and ALMs (71.2%) than in RW aircrew (56.6%) ($p < 0.05$). The presence of neck pain in aircrew at the time of completing the questionnaire was 14.6% for all aircrew or, individually, was 16.1% for FJ, 12.6% for RW, and 16.5% for ALM.
- Rotary-wing aircrew reporting neck pain had flown significantly more hours than RW aircrew without neck pain ($p < 0.05$). There were otherwise no differences in flying hours between groups with or without neck pain when all aircrew were combined, or for FJ and ALMs alone.

Associated Factors of Neck Pain

- Fast-Jet

A significant association was shown between occupational prevalence of neck pain and work well-being ($\chi^2 = 12.42$, 3 df; $p < 0.05$). Regression analysis demonstrated a reduction in the probability of neck pain with an increase in work well-being score. No other associations were identified.

- Rotary Wing

In RW, increased total number of NVG flying hours was associated with an increased probability of having suffered flight-related neck pain ($\chi^2 = 15.31$, 1 df, $p < 0.05$). RW front aircrew who had flown over 700 hours using NVGs had more than an 80% likelihood of developing neck pain, compared with less than 53% for those aircrew with fewer than 200 hours flown with NVGs. Rotary-wing aircrew least likely to have suffered neck pain were those who participated in daily aerobic exercise (38%).

- Air Loadmasters

Occupational prevalence of neck pain was positively associated with NVG use ($\chi^2 = 15.36$, 1 df; $p < 0.05$) and well-being lifestyle factors in ALMs ($\chi^2 = 6.84$, 1 df; $p < 0.005$).

Perceived Causative Factors

- Over 80% of FJ aircrew associated flight-related neck pain with high G, whereas RW most commonly associated neck pain with poor posture (>60%). Likewise, ALMs attributed poor posture to their neck pain (>90%), but vibration and NVGs were also believed to be a problem in over 70% of ALMs.

Treatment

- Of all aircrew who reported flight-related neck pain, only 26.6% sought treatment for their pain. A higher percentage of FJ pilots sought treatment than did RW and ALMs (30.7%, 22.3% and 21.3%, respectively). The pattern of treatment sought is similar across the different types of aircrew. Treatment by a physiotherapist was most popular for all aircrew.

6.3.1.2 Study 2 – The Effects of Whole-Body Vibration and Head Loading on Neck Muscle Function in Rotary-Wing Air Loadmasters

6.3.1.2.1 Introduction and Aims

The physically demanding nature of the tasks that ALMs perform and the requirement to wear heavy loads on the head (e.g., helmet, NVGs), are likely to be major contributory factors to the high prevalence of flight-related pain. Operational sorties may last up to 3 to 4 hours, where aircrew are exposed to whole-body vibration (WBV). The WBV characteristics are more extreme on the Chinook than any other aircraft, where the risk of flight-related neck pain is also the greatest.

The cyclic mechanical loading imposed on the musculoskeletal structures by WBV is believed to be a key contributory factor to the onset of pain. Some, but not all studies have shown a development of fatigue when exposed to WBV, but others have shown that WBV can have a positive effect on neuromuscular function. However, exposure to WBV is prolonged and recovery between sorties may be inadequate, which may lead to muscle fatigue and increased loading of the bony structures of the spine.

Therefore, the aim of this study was to examine the effect of WBV and head loading on neck and lumbar spine muscle activity in ALMs.

6.3.1.2.2 *Methods*

Ten experienced Chinook ALMs volunteered to participate in the study. Subjects were required to have a status of 'fit to fly', including being currently free from neck pain, and experience of wearing NVGs for at least 12 months.

Subjects completed three experimental sessions that were presented in a randomised order. C1 – helmet (Mk4) without vibration; C2 – helmet with vibration; C3 – helmet with NVGs and counterbalance weight, with vibration. Under conditions C2 and C3, subjects were exposed to a 2.5-hour vertical (+Gz) vibration profile recorded from a Chinook helicopter in the cruise phase of flight.

During each condition, volunteers sat on an ammunition ('oils') box (used as a crewman seat in the rear of the Chinook), that was securely mounted on top of a man-rated vibration platform, for a period of 2.5 h. At 10 min intervals, volunteers were required to perform an observation drill designed to simulate the bilateral head rotation movements made by ALMs during observation tasks whilst aboard a Chinook. The observation drill required the subjects to align a helmet mounted laser beam with seven targets located around the platform.

Before and immediately after the 2.5 h exposures, force production and electrical activity of the neck flexor and extensor muscles were measured. During the exposures, cervical muscle activity was recorded during the observational drills at the start and end of the 2.5 h duration. Ratings of perceived discomfort were also recorded at 30 min intervals during the exposures.

Fatigue of the cervical muscles was determined from changes in the force production and changes in electromyographic (EMG) signals obtained during maximal voluntary contractions and during the observation drill. An increase in the root mean-square (RMS) amplitude and decrease in the median power frequency (MDF) of the EMG signal are indicative of muscle fatigue.

6.3.1.2.3 *Results*

- Maximal force production decreased by 14% during neck flexion under the helmet and no vibration condition ($p=0.01$), and by 9% during neck extension under the helmet with vibration condition ($p<0.05$) (Figure 6.1) after 2.5 h. There were no significant differences in RMS values or median power frequency content before and after exposure for any of the neck muscles analysed and under any of the experimental conditions.
- During the observation drills, no differences in the RMS were shown.

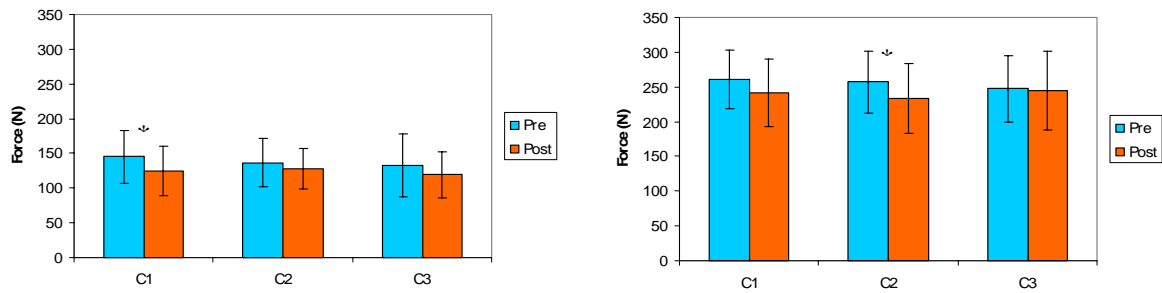


Figure 6.1: Mean (SD) Maximum Force Production During Neck Flexion (left) and Neck Extension (right), Pre- and Post-exposure. (*denotes a significant difference between pre- and post- exposure, $p < 0.05$). (C1: helmet, no vibration; C2: helmet, with vibration; C3: helmet + NVGs, with vibration).

6.3.1.2.4 Conclusions

Exposure to WBV for 2.5 h, representative of the frequency range of the Chinook, did not induce fatigue of the cervical or lumbar muscles in ALMs when wearing either a helmet alone or with helmet and NVGs. These findings suggest that flight-related neck pain reported by rotary-wing ALMs flying 2.5 h sorties may be attributed to other factors, such as posture and role-specific tasks. The combined effect of WBV and relevant operational postures on muscle fatigue therefore warrants further investigation.

6.3.1.3 Study 3 – The Effect of Aircrew Helmet Mass Properties on Neck Muscle Activity and Fatigue, Aircrew Performance and Helmet Acceptability

6.3.1.3.1 Introduction and Aims

Helmets reduce the risk of head-impact injury in accidents, but at the expense of increased head-borne mass. Increasing head-borne mass of aircrew places greater stress on the neck musculature and, consequently, the risk of developing neck pain and injury during flight. Also, aircrew helmets are used as a mounting platform for other devices to enhance pilot performance but the addition of equipment alters its centre of gravity. Specifications of future helmets include a reduction in mass although specific mass properties, such as centre of gravity, have been defined only for safe ejection. No specific guidance is provided on moment of inertia and, furthermore, there are no requirements for rotary-wing helmets. Appropriate technology exists to significantly reduce helmet mass, but recommended mass limits and associated centre of gravity and inertia considerations are not available. Measurements of neck muscle activity and strain (percentage of maximal effort) is often used to investigate the aetiology of neck pain under different flying conditions (e.g., exposure to G; Wickes and Greeves, 2005, *Aviat Space Environ Med*, 76, P217), however, there are no studies that have systematically examined the relationship between helmet mass, centre of gravity position and moment of inertia on neck muscle function. These data will provide guidance for future helmet design specifications.

The aim of the study was to explore the relationship between neck muscle activity, fatigue and endurance. The time course of fatigue in those muscles responsible for supporting the human head under different applied moments was also investigated.

6.3.1.3.2 Methods

Six males (mean (1SD) age 33.1 (11.4) yr) were recruited to participate in the study. Subjects were selected if they had the head dimensions to fit a medium Mk10B aircrew helmet. Subjects were required to visit the laboratory on eight separate occasions, forming eight experimental conditions. On each occasion, maximal and sub-maximal isometric contractions of the neck muscles during extension and flexion were obtained with the subjects seated in upright position and with the head in the neutral position.

Three maximal isometric contractions and three repeated sub-maximal contractions at 20%, 40%, 60% and 80% of maximum were performed. Unilateral muscle activity amplitude and median density frequency (MDF) were obtained for the cervical *Erector Spinae* and *Splenius Capitis* during extension conditions and the *Sternocleidomastoid* during flexion conditions.

Subjects performed a single neck moment test session on a tilt table, orientated at different angles in supine and prone positions (Table 6.1). The subjects were required to maintain neutral head position until volitional fatigue, up to 60 min. The test was terminated when the head could no longer be held in the neutral position, indicating the onset of fatigue.

Table 6.1: Angle and Moments Acting on C7 for Each Experimental Condition

Condition	Tilt Table Angle to Vertical (°)	Nominal Moment at C7 (Nm)
A	- 90	- 9.67
B	- 60	- 8.06
C	- 30	- 4.28
D	- 10	- 1.05
E	10	2.31
F	30	5.39
G	60	8.69
H	90	9.67

The angle of the tilt table was altered on eight separate occasions to allow the application of different moments to the muscles that support the head and neck. This was achieved by protruding the subject's head and neck (from C7) over the edge of the table, so that the mass of the head and neck complex was supported solely by the neck muscles. Four flexion and four extension moment test conditions were performed, with the subject oriented between prone and supine. The order of tests was presented in a randomised manner. The maximum moment of force (Condition H) acting at the C7 vertebrae was equivalent to a 2.6 Gz excursion when wearing a Mk10B helmet (Table 6.1).

The four flexion and extension moment test conditions exerted the following nominal moments (based on the geometry of a 50th percentile HIII test dummy) at the C7 vertebrae.

6.3.1.3.3 Results

- The time to failure decreased with increasing flexion moments. Significant differences for the time to failure were observed between all flexion conditions (Condition A = 131.5 (57.3) s; Condition B = 195.2 (102.9); Condition C = 698.1 (544.6) s; Condition D (3230.2 (930) s). The time to failure was longest for Condition D (p<0.05).
- There were no significant differences in time to failure between the head extension conditions.
- *Sternocleidomastoid* activity during flexion increased significantly over time for each condition, A to D (p<0.05). Furthermore, the overall increase (from start to finish) in *Sternocleidomastoid* activity for these conditions was significantly greater for Conditions A to C, with the highest moments, compared with Condition D, the lowest moment (p<0.05).
- The normalised activity level of the *Sternocleidomastoid* for flexion conditions A to D averaged across all subjects was 43.9%, 42.7%, 22.1% and 2.1% of maximum activity, respectively.

- In flexion, MDF of the *Sternocleidomastoid* activity tended to decrease over time but this did not reach statistical significance ($p=0.05$).
- No significant differences were shown between the extension conditions for muscle activity or MDF for the *Erector Spinae*.
- The normalised activity level of the *Erector Spinae* for extension conditions E to H averaged across all subjects was 4.3%, 6.7% 7.2% and 24.9% of maximum activity, respectively. The normalised activity level of the *Splenius Capitis* for extension conditions E to H averaged across all subjects was 2.7% 7.9% 8.1% and 30.7% of maximum activity, respectively.
- A relationship between muscle activity and time to failure was obtained for the *Sternocleidomastoid* by plotting the gradient of the activity against average time to failure for each flexion test condition. Likewise, the gradient of the normalised MDF was plotted against average time to failure for each flexion test condition. The rate of change of MDF was related to the time to failure. With the current *Sternocleidomastoid* data, there is a strong relationship between the rate of change of activity and MDF against time, and the time to failure.

6.3.1.3.4 Conclusions

- The magnitude of applied moments were similar for the flexion and extension conditions, but the time to failure data, and muscle activity levels showed that the flexion conditions imposed a greater strain on the neck musculature and were much more demanding. The activity of the neck muscles during the flexion conditions was at a sufficient level for fatigue to occur (over 40% of maximal activity for most demanding conditions) whereas this was generally not the case for the extension conditions (less than 10% of maximal activity for least demanding conditions).
- These results indicate that any helmet design that results in a rearward moment for the head and helmet together is undesirable. Current helmets have a slight forward moment, but extended head positions, supine postures and incorrect applications of counterbalances can produce a rearward moment.
- A decrease in MDF is an indicator of fatigue. The flexion conditions showed a trend for decreasing MDF with time for larger moments but this was not statistically significant, due possibly to the low sample size.
- The extension moments applied in this study were not sufficient enough to elicit volitional fatigue in all subjects in less than 60 min.
- The results demonstrate a possible methodology for predicting the time to failure for neck muscles, based on characteristics of the EMG signal, for a statically applied moment, with the head and neck in the neutral position. Such a relationship is useful for the purposes of assessing the effects of helmet mass properties as it provides a means of estimating time to failure based on a small sample of neck muscle activity data, alleviating the need to test all conditions to point of fatigue.

6.3.2 Work in Progress

6.3.2.1 Study 4 – The Effect of Training on the Hawk Fast-Jet on Neck Muscle Function and Symptoms of Neck Pain in UK Student Pilots

6.3.2.1.1 Introduction and Aims

Fast-jet and rotary-wing aircrew are at a high risk of developing flight-related neck pain. Survey studies have shown that fast-jet aircrew most commonly associate acute neck pain with high G loading; rotary-wing aircrew attribute neck pain to wearing head-loading equipment, which is more likely caused by local

muscle fatigue due to prolonged exposure to low loads. Neck pain patients typically demonstrate reduced strength, altered activation patterns, and increased fatigability of the cervical muscles that result in poor support and potential overload of cervical structures. Impaired muscle function may also play a critical role in the aetiology of flight-related neck pain in aircrew, and the prevention and rehabilitation of neck pain may therefore be most effectively managed through the prescription of appropriate exercise to restore muscle function. However, the role of impaired neck muscle function in the aetiology of flight-related neck pain in aircrew has not been fully investigated. Furthermore, the effects and potential benefits of flying training on neck muscle function have not been examined.

The aims of this research program are therefore to establish the incidence of neck pain in student fast-jet pilots and to examine the changes in neck muscle function of pilots undergoing Advanced Flying Training (AFT) and Initial Tactics and Weapons (ITW) training on the Hawk T1 trainer.

6.3.2.1.2 Progress

A prospective study is in progress monitoring the incidence of neck pain and changes in neck muscle function of student aircrew undertaking AFT (208 Sqn) and ITW (19 Sqn) training on the Hawk T1 trainer. The risk of neck pain during ITW is particularly high due to the high G manoeuvres that students perform as part of their training (Averty and Green, 2005, *Aviat Space Environ Med*, 76, P217).

Using a Multi-Cervical Unit (BTE Technologies, US), muscle function assessments are being conducted at the start and end of training. Muscle function assessments include cervical range of movement (cROM) in flexion, extension, rotation and lateral flexion. Measurements of maximal force production are being obtained at head angles relevant those adopted during flight (Figure 6.2). All volunteers are issued with a diary to capture any daily experiences of neck pain.



Figure 6.2: Head Positions during Isometric Strength Tests in Student Pilots at RAF Valley.

Preliminary results show that even before fast-jet training on the Hawk T1 trainer, cROM of student pilots are between 1.7% and 20% greater than normative values (i.e. higher than an age- and sex-matched populations). Initial data also suggest that pilots are particularly strong in neck extension and above population norms in all measures of isometric neck strength.

6.3.3 Other Ongoing Relevant Activities

A study has been conducted at the RAF fast-jet training unit investigating changes in bone mineralisation of the cervical spine in response to G exposure. Data collection is complete and the report is in preparation.

The RAF has an ongoing project (from August 2006 to September 2007) determining the need for physiotherapy for aircrew on the new Typhoon aircraft. Existing services offered to aircrew and their rehabilitation requirements on Typhoon are being examined. Initial findings have shown that Typhoon aircrew have:

- No assessment of neck strength or stability;
- No postural assessment;
- No direct access to physiotherapy;
- A reluctance to visit medical centres; and
- No specific training agreed by physical education specialists and medical services.

Physiotherapy on Typhoon squadrons is recommended to provide one-to-one treatment; prepare aircrew for 'fit for role'; conduct follow-up assessments at every stage of training; and to offer continuous advice and training.

6.4 UNCLASSIFIED REPORTS/PUBLICATIONS/PRESENTATIONS AVAILABLE FOR DISTRIBUTION

6.4.1 Reports/Publications/Proceedings during the Previous 4 Years

Wickes, SJ, Greeves, JP. *Prevalence and associated factors of flight-related neck pain*. QinetiQ Report Number: QinetiQ/06/01069. 2006.

Parker PK, Coyles VR, Day SE. *Investigation into the effect of helmet mass properties on the performance of aircrew in a vibration and +Gz environment*. QinetiQ Report Number: QinetiQ/06/00457. 2006.

Coyles VR. *The effects of whole-body vibration and head loading on neck muscle function in rotary-wing air loadmasters*. QinetiQ Report Number: QinetiQ /05/01735. 2005.

Averty C, Green ND. Prevalence of high-G neck injury in fast-jet flying instructors. *Aviat Space Environ Med* 2005; 76:P217.

Wickes S, Greeves J. The effect of night vision goggles on neck muscle activity during Gz exposure. *Aviat Space Environ Med* 2005; 76:P217.

Greeves JP, Coyles VR, Myers SM, Lee VM. Head loading and neck pain in helicopter rear aircrew. In: *Proceedings of the NATO RTA 'Equipment for Personal Protection' (AVT-/RSM-012)*. Koblenz. 2003.

Greeves JP, Coyles VR, Strange A. *Initial report into the physical demands placed upon rear aircrew within UK military aircraft and conditions when risk of injury or reduced performance may be increased*. QinetiQ Report Number: QinetiQ/04/01185/1.0. 2004.

Wickes SJ. *The effect of aircrew helmets and helmet-mounted equipment on human neck muscle fatigue and injury*. QinetiQ Report Number: QinetiQ/KI/CHS/TR030611/1.0. 2003.

Wickes SJ, Coyles VR, Shah S, Greeves JP. (2003) Neck muscle activity during +Gz loading in men and women. *Aviat Space Environ Med* 2003; 74:P399.

6.4.2 Lay Articles

Greeves JP. Flying – A Pain in the Neck for Aircrew. Aviate. Summer, 2006.

6.4.3 Recent Communications

Greeves JP. Head loading and neck pain in UK military aircrew. Presentation to SAFE Europe, March 2007.

Wickes SJ, Greeves JP. Occupational and lifestyle contributors to flight-related neck pain. Presentation to the Aerospace Medical Association, May 2006.

6.4.4 Presentations at the Neck Pain in Aircrew Workshop, March 2007, Organised and Hosted by QinetiQ Ltd.

Greeves, J.P. Efficacy of Neck Strength Training in Managing Neck Pain.

Wickes, S.J. Neck Pain in UK Aircrew: Reporting and Treatment.

Day, S. and Foreman, A. Reducing Head-borne Mass.

Green, N. Is there a Role for Education in the Prevention of Neck Pain in Aircrew?

Beach, C. Current Physiotherapy Treatments for Neck Pain in Aircrew.

Kelly, L. Is there a Future for Physiotherapy within the Typhoon Squadron?

6.5 FUTURE DIRECTION OF WORK PROGRAMME

Future work programs aim to merge the research on cervical injuries with other musculoskeletal injuries, including the lumbar region, to identify all contributory factors and the physical stressors of the flying environment across different platforms. The program also aims to gain improved understanding of the role of neck conditioning in reducing the symptoms of neck pain. Specific research focus on the cervical region will be conducted to provide guidance on the specifications for future helmet designs.

Chapter 7 – REVIEW OF THE US AIR FORCE NATIONAL WORK PROGRAMME ON THE LONG TERM EFFECTS OF SUSTAINED HIGH G ON THE CERVICAL SPINE

by

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7.1 BACKGROUND FOR CURRENT NATIONAL PROGRAMME

There has been much interest among the agencies in the Department of Defense (DoD) in learning the effects of heavier helmet systems and how to reduce or eliminate neck pain or injury. Researchers from the Air Force are collaborating with their counterparts from the Army and Navy. These groups are also represented in meetings of scientists of NATO countries and the TTCP who lead research efforts of their own.

7.2 SUMMARY REPORT – LONG TERM FATIGUE RELATED TO HEAVY HELMET SYSTEMS

AFRL/HEPG recently conducted a helmet biodynamics research program that focused on finding gender differences in response to “heavier helmets” under high G acceleration. In that effort, the female test subjects used approximately 80% of their maximal voluntary contraction (MVC) in neck extension. The males used only about 30% of their maximal effort (Eveland ES, Goodyear C. **Neck muscle response to changes in helmet loading under +Gz acceleration – gender differences**. USAF Technical Report AFRL-HE-WP-TR-2002-0211, June 2001). Since then, flight line testing, intended to examine indications of muscle fatigue during flight have been conducted. There was not enough data to draw definite conclusions after these tests but the goal was to compare results using helmets currently in use with developmental versions of helmet systems. The acquisition process can benefit from knowledge of how new systems affect the humans using them and how the results might differ from those already in use.

Examination of neck muscle fatigue is continuing but, in AFRL/HEPG, the focus is shifting away from high G acceleration to longer duration. The emphasis is on finding the effects of multiple missions over longer time on the human user. There is interest in fast jets as well as slower movers that might be in flight for long periods. Those slower movers might have even heavier helmets than those used in the jet aircraft. The latest HEPG research utilizes this scenario to investigate how a proposed heavier helmet might be tolerated compared to a system in use now. The upper weight limit of the helmet system represents the upper limit proposed for a new design. The goal of the research effort is to determine if that helmet affects the human user differently than a lighter helmet system in use. That information will serve as guidance for design criteria and the developers.

In the most recent HEPG scientific research, data was collected from eight male and four female military volunteers. These data are from four basic sets and include neck muscle maximal volunteer contractions (MVCs) in extension, endurance based on sustained extensions pulling against 70% of their baseline MVC, a target recognition task, and a target acquisition task. Volunteer test subjects were seated for MVC determination. They were given three attempts to pull against a load cell using a strap connected using a

weight-lifting style head harness. The attempt generating the highest force was considered the MVC. Endurance testing was done using 70% of this MVC. A computer display provided a subject feedback indication of force level. Subjects maintained force between horizontal limit lines. Subjects were asked to pull until could no longer keep the indicator between the lines.

The next two tests were related to findings targets. The first required subjects to examine a series of 50 computer screens containing random mixes of red squares and blue circles. One distinctive target (red circle) was included on some screens. The goal was to examine each screen and decide if this target was present. Responses were recorded from keystrokes on a keyboard. Time to make the decision, up to 5 seconds, was also recorded. The final test took place in a static cockpit simulator. A visual system provided targets projected for the subjects via a display within a set of goggles. The simulations required the subjects to move their heads in response to pointers extending out toward the target from the center of a set of crosshairs. Subjects saw target aircraft at various locations forward and out to the sides of the cockpit. Their chore was to find each target, hold the pair of crosshairs on it, and move on to the next target in the least time possible. Time and position data was saved to allow examination of time taken to complete the task.

Baseline data (A) was collected at the beginning of each test day for all of the four tests. After that, each subject was exposed to a high-G acceleration profile based on data taken from Nellis AFB Red Flag training flights. The profiles controlled the G load experienced in the Dynamic Environment Simulator (DES), a man-rated, human use centrifuge. The profile contained a mix of low G exposure near the beginning and higher loads later, as if they travelled to a mission then engaged the adversary. A second set of data was collected after this exposure (B) and again after a second similar high-G exposure later in the day (C). A final, fourth, data set (D) was collected at the end of the day, after the subject performed a static flight simulator period with no high-G exposure. Data collection and strength measurements were done as soon as possible after each exposure. Helmets were worn for approximately 6 hours over the day, with limited removal during times set aside for lunch breaks.

Indications show that subjects were physically fatigued as illustrated by changes in MVC and endurance over test days. Preliminary results have not yet provided answers to questions such as “Is fatigue more prevalent with one helmet than another?” or “Is fatigue more evident after 2 DES exposures?” or “Does a short time with no G exposure allow significant recovery” or “Does target tracking or acquisition skills degrade as a result of the fatigue experienced”? Those analyses, as well as examination of electromyography (EMG) remain to be accomplished.

Chapter 8 – REVIEW OF NATIONAL WORK PROGRAMME ON THE LONG TERM EFFECTS OF SUSTAINED HIGH G ON THE CERVICAL SPINE – THE NAVAL AIR SYSTEMS COMMAND (NAVAIR) PATUXENT RIVER, MARYLAND

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8.1 BACKGROUND FOR CURRENT NATIONAL PROGRAMME

The use of head-supported devices, e.g., night vision goggles (NVG), during long duration missions or while exposed to repeated shock, ejection, and crash may increase the risk of spinal injury. In addition to supporting heavy loads that alter the head's centre-of-mass, factors that affect injury tolerance include age, gender, work/rest cycle, and behaviour. Limited applicable risk criteria exist due to specific gaps in our knowledge of spinal injury in aerospace environments. The US Office of Naval Research (ONR) sponsors a multidisciplinary effort led by NAVAIR to quantitatively determine spinal injury risk. To fill those gaps, this effort includes studies to define those critical criteria in order to develop a model that can be used to help design protective systems that improve performance without undue injury risk. Starting in FY05, ONR has expanded the scope of the program to include the entire spine. Data collection on the lower spine has begun while the current focus is on completing the cervical spine.

8.2 SPECIFIC RESEARCH TOPICS UNDER INVESTIGATION

- Develop a Spinal Injury Prediction Model;
- Quantify aircrew neck pain through distribution of anonymous survey based on US Army and Canadian questionnaires;
- Determine relationship between isometric and dynamic neck strength and endurance; and
- Develop a Parachute Opening Shock Emulator (POSE).

8.3 BRIEF DESCRIPTION OF STUDIES AND RESULTS

8.3.1 Prediction and Prevention of Spinal Injury during Naval Operations

The following is a brief summary of the progress made in determining the geometric, materials properties and constitutive equations describing spinal hard and soft tissues sub-failure and failure responses. These data were obtained during quasi-static and dynamic conditions using post mortem human specimens whose age and size are appropriate to US naval aviators. Live subjects also participated in two studies involving quantitative computerized tomography (QCT) and magnetic resonance imaging (MRI). Combined, the results have been used to develop an anatomically based parameterized probabilistic model of the spine, enabling the development of injury risk estimates. These predictions can then be used to develop design guidelines for head supported systems, seating, and survival equipment.

- 1) Determined male/female vertebral geometric and bone mineral density properties using spiral QCT.
- 2) Determined 3-D geometrical cervical properties on one male and two female specimens using sequential cryomicrotome sectioning.
- 3) Determined cervical hard/soft tissue mechanical properties using specimens whose age and anthropometrics represent naval aviators under static, quasi-static, and dynamic conditions.
- 4) Determined macro/micro failure properties and viscoelastic response of cervical ligaments and intervertebral discs (IVD), including age-based soft tissue differences and ligament viscoelastic temperature dependency:
 - a) Using a custom made spherical indenter to characterize IVD response characteristics, viscoelastic analysis results indicated no statistically significant difference based on disc location or spinal level.
- 5) Designed a novel fixture to determine major neck muscles architectural properties, moment arms and centroids.
- 6) Testing began on live volunteers using a custom fixture to simulate an ejection seat to determine the effects of added head weight on soft tissue loading using an up-right MRI.
- 7) Probabilistic Injury Model Development:
 - Probabilistic modelling approach accounts for uncertainties that cannot be handled using deterministic methods;
 - Parameterization permits rapid generation of individual subject finite element models, FEM, (e.g., small female vs. large females). Enables investigation of deterministic and probabilistic sensitivities of geometric perturbations to injury prediction;
 - Using a parametric approach, a personalized FEM using QCT scans of any individual can be created in a few hours;
 - Completed finite element models of C0 – C7 vertebral bodies, ligaments, and discs of small and large-sized males and females;
 - Integrated hierarchical verification/validation approach (V&V) confirmed model performance at increasing levels of complexity;
 - Material model parameters represent quasi-static and dynamic viscoelastic behaviour of soft tissue and IVD at the component level. Parameters are adjusted so simulated material behaviour represents experimentally observed behaviour. These parameters are used in more complex hierarchical level models (cervical motion segments and full cervical spine) without adjustment

using boundary conditions that simulate laboratory tests of similar components. Model performance is then compared to experimentally observed responses;

- Model kinematic response of motion segments and C3-T1 compared well to the experimental data for all four weight groups in flexion, extension, axial rotation, and lateral bending; and
 - Began developing thoracic and lumbar vertebrae motion segment model (T11-L2) using statistical shape modelling technique.
- 8) Began development of a probabilistic assessment tool to relate risk of anatomic injury to the neck; includes the development of an injury hierarchy and hazard methodology; for sub-catastrophic injuries, focus is on nerve involvement and degree of recruitment of cervical components.
- 9) Reanalyzed, verified and certified Naval Biodynamics Laboratory (NBDL) impact datasets for model validation. These data were collected from the 1970's to 1990's on young healthy volunteers exposed to millisecond pulses in the x, y and z planes.

8.3.2 Quantify Aircrew Neck Pain through Anonymous Survey

This is a joint project between NAVAIR and the US Naval Safety Center that distributes an anonymous survey to pilots and aircrew to determine the extent and magnitude of neck pain associated with flight operations in naval fighter jet, helicopter, attack, and fixed wing aircraft. The survey, which is based on instruments previously used by the US Army and DRDC-Toronto, Canada to determine neck pain in helicopter aircrews, was expanded to also include fast jet, attack, and fixed wing aircrews.

Questions included:

- Age, gender, weight, height, exercise (type and frequency);
- Crew position, instructor status, flight hours and aircraft type;
- Helmet type, NVG use (type, total and recent number of hours);
- Any occurrence of pain unrelated/related, during and after flying;
- Pain associated with particular flight maneuvers and/or G load;
- Pain associated with equipment other than head mounted;
- Quantify severity of pain: worst and average;
- Quantify persistence of symptoms: worst and average;
- Description of treatment and type of care provider, if any;
- Quantify whether aircrew were removed from flight status due to neck pain;
- Actions taken to alleviate neck pain; and
- Comments.

Preliminary results are presented in Table 8.1.

**Table 8.1: Surveys are Currently being Distributed and Data Analysis Pending
 (Preliminary results from 148 fighter jet, 78 attack, 159 helicopter,
 and 15 fixed wing pilots and crew follow)**

	Fighter Jet	Attack	Rotary	Fixed Wing
Male	144	69	148	15
Female	4	9	11	0
Age (year) ¹	31.8 ± 4.7	31.2 ± 5.1	30.3 ± 5.7	30.5 ± 6.1
Height (in) ¹	71.4 ± 3.2	70.2 ± 3.2	70.5 ± 2.7	70.3 ± 2.0
Weight (lbs) ¹	183.6 ± 21.6	177.9 ± 26.0	180.8 ± 23.6	186.9 ± 20.1
Flight hours ¹	1342 ± 857	1178 ± 893	1386 ± 990	1275 ± 896
Number Performing Exercise				
Aerobic	147	75	156	15
Weight lifting	129	61	61	13
Neck exercises	59	17	50	13
Crew Position				
Pilot	92	28	103	6
Crew Chief			48	
Other	35	53	7	9
Instructor	37	23	60	8
Number using NVG				
	145	72	150	0
Total Hours ¹	30.2 ± 102.2	84.2 ± 77.8	189.7 ± 162.1	
Hours worn during last 28 days ¹	1.8 ± 2.5	2.7 ± 3.0	3.1 ± 4.0	
Average wear time (hr) ¹	1.4 ± 0.7	1.7 ± 0.8	2.7 ± 0.7	
Pain Incidence				
Unrelated to Flying ²	43 (29%)	23 (29%)	56 (35%)	1 (7%)
Related to Flying ²	89 (60%)	41 (53%)	94 (59%)	8 (53%)
Associated with Flight Manoeuvres ²	59 (40%)	27 (35%)	18 (11%)	5 (33%)
No. Reporting Pain During Flight ²	71 (48%)	39 (50%)	70 (44%)	7 (47%)
No. Reporting Pain After Flight ²	81 (55%)	31 (40%)	73 (46%)	5 (33%)
Persistence Worst Pain				
Up to 24 hours	32	25	57	3
1 – 4 day post flight	43	10	17	4
> 4 day post flight	16	0	3	1
Persistence Average Pain				
Up to 24 hours	49	24	59	4
1 – 4 day post flight	26	7	6	2
> 4 day post flight	3	0	1	0

¹: Mean ± one standard deviation; ²: Number and percentage of total respondents per platform indicating pain.

8.3.3 Determine Relationship between Isometric and Dynamic Neck Strength and Endurance

1) **Objective:**

- Determine the subjective limits of peak dynamic strength and endurance of the human cervical spine;
- Objectively measure dynamic strength and fatigue limits using electromyography (EMG);
- Determine the relationship between the ability to maintain a consistent dynamic effort during various work/rest cycles; and
- Develop a model to predict isometric neck muscle strength and endurance from dynamic responses.

2) **Approach:** Conduct basic research to determine the subjective tolerance limits of the human neck to support increasing loads in order to help establish guidelines for the development of head borne devices which will accommodate the expanded male and female aircrew population.

3) **Project Status:** Under a previous ONR ILIR (In-house Laboratory Independent Research) program, the test fixture was designed, constructed, and isometric data was collected on 23 volunteers. Currently additional volunteer data is being collected to develop a validated model of neck strength and endurance.

8.3.4 Development of a Parachute Opening Shock Emulator (POSE)

1) **Background:** The most hazardous phase during ejection occurs when the parachute separates the aviator from the seat. Depending upon the initial position of the seat and the aviator within the seat, the linear and angular deceleration of the body may be aggravated as it is twisted and snatched into alignment with the parachute's opening vector. Currently, this can only be examined during expensive system level rocket sled testing (>\$250K per test). As a consequence, at best only a few data points are obtained to base programmatic decisions on. Development of a highly repeatable, horizontal accelerator (HA) based method of simulating this event provides a cost effective means to comprehensively analyze the variables that define the parachute opening shock over the entire, representative ejection airspeed envelope.

2) **Objective:** The objectives of this project are to:

- Develop the capability to simulate the parachute opening shock phase of an ejection under controlled, repeatable conditions;
- Develop the methodology and a model to correlate experimental acceleration profiles to known ejection airspeeds; and
- Determine the relationship between full body acceleration, body orientation, aviator size, and measured cervical loads and moments.

Ultimately, the goal of this investigation is to gain an understanding of the dynamics and kinematics involved during one of the most complex phases of an ejection and to quantitatively determine the tolerance limits of the human cervical spine to parachute opening shock. The information gained during this study will be invaluable in helping establish guidelines for the development of head-borne devices, both in respect to airspeed limitations and aviator size.

3) **Results/Status:** During the last two years, the POSE fixture design was verified through dynamic computer simulation and structural analysis. Fabrication has been completed and a stand-up demo occurred on 23 APR 07.

- 4) **Planned Activities:** HA integration issues will be resolved, preliminary testing will begin in summer, 2007. Baseline tests will be conducted to validate the concept. Data will be analyzed and compared to computer simulation predictions to refine the design. Final testing will investigate occupant initial position (seat pitch), ejection airspeed (correlated by varying acceleration profiles and riser length and material), helmet mass/properties, and aviator size. Modifications to the existing structure will be explored to provide seat yaw control, in addition to pitch, to improve fidelity of fixture to replicate free-stream ejection seat motion.

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8.5 FUTURE DIRECTION OF WORK PROGRAMME

- Develop a probabilistic assessment tool to determine the risk of anatomic injury to the neck;
- Continue neck strength studies and development of isometric-dynamic response model;
- Continue POSE development and conduct studies; include yaw capability;
- Expand cervical model to complete spine, including high fidelity lumbar and thoracic spines;
- Determine effects of aging on soft tissues;
- Add high fidelity representation of the neck and lumbar musculature, including moment arms, wrapping, angles, architecture, activation, force; and
- Expand model to include high fidelity skull and include capability to predict non-penetrating traumatic brain injury resulting from blast exposure.



REPORT DOCUMENTATION PAGE																			
1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document																
	RTO-TR-HFM-083 AC/323(HFM-083)TP/205	ISBN 978-92-837-0055-5	UNCLASSIFIED/ UNLIMITED																
5. Originator	Research and Technology Organisation North Atlantic Treaty Organisation BP 25, F-92201 Neuilly-sur-Seine Cedex, France																		
6. Title	Review of National Work Programme on the Long Term Effects of Sustained High G on the Cervical Spine																		
7. Presented at/Sponsored by	This Report of the Task Group HFM-083 documents a review of national work programme concerning adverse effects on the cervical spine related to high sustained G in high performance aircraft and attack helicopters.																		
8. Author(s)/Editor(s)	Karin Harms-Ringdahl, PhD, RPT (Editor)		9. Date December 2008																
10. Author's/Editor's Address	Karolinska Institutet, Department of Neurobiology, Care Sciences, and Society, Stockholm, Sweden		11. Pages 56																
12. Distribution Statement	There are no restrictions on the distribution of this document. Information about the availability of this and other RTO unclassified publications is given on the back cover.																		
13. Keywords/Descriptors	<table style="width: 100%; border: none;"> <tr> <td style="width: 50%;">Acceleration tolerance</td> <td style="width: 50%;">Human factors engineering</td> </tr> <tr> <td>Aerospace medicine</td> <td>Injuries</td> </tr> <tr> <td>Anatomy</td> <td>Loads (forces)</td> </tr> <tr> <td>Biomechanics</td> <td>Neck (anatomy)</td> </tr> <tr> <td>Exertion</td> <td>Physiological effects</td> </tr> <tr> <td>Flight maneuvers</td> <td>Spine (anatomy)</td> </tr> <tr> <td>Head (anatomy)</td> <td>Stress (physiology)</td> </tr> <tr> <td>High performance aircraft</td> <td>Tolerances (physiology)</td> </tr> </table>			Acceleration tolerance	Human factors engineering	Aerospace medicine	Injuries	Anatomy	Loads (forces)	Biomechanics	Neck (anatomy)	Exertion	Physiological effects	Flight maneuvers	Spine (anatomy)	Head (anatomy)	Stress (physiology)	High performance aircraft	Tolerances (physiology)
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Head (anatomy)	Stress (physiology)																		
High performance aircraft	Tolerances (physiology)																		
14. Abstract	<p>Empirical evidence, as well as long term studies with radiographic techniques, suggests that flying high performance aircraft has an adverse effect on the cervical spine of aviators. The RTO Group HFM-083 was created to determine the extent of the effects due to long term exposures to sustained G levels and to develop mitigation recommendations. Contributing nations have focused on diverse aspects of the problem, such as Aircrew questionnaires, countermeasures, treatment, characterization of the spinal pain beyond questionnaires, muscular activity (EMG), imaging (MRI), and modelling. Recommendations for future work are provided.</p>																		





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