Measuring Neuromuscular Fatigue in Cervical Spinal Musculature of Military Helicopter Aircrew

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ABSTRACT Neck pain and muscle function in aircrew have received considerable attention. We hypothesized normalized electromyography (EMG) frequency would provide insight into appropriate methods to assess muscle fatigue in helicopter aircrew. Methods: 40 helicopter aircrew performed isometric testing that included maximal voluntary contractions (MVC) and 70% MVC endurance protocols of extension, flexion, and left and right lateral flexion for cervical muscles. Bilateral muscle activity in the splenius capitis, sternocleidomastoid, and upper trapezius was monitored with EMG. Normalized mean EMG frequency was calculated for each muscle at the start and end of the 70% MVC trials to determine which muscles fatigued and limited force maintenance during each isometric movement. Results: For extension, the left and right splenius capitis fatigued by ~21–22% ($p < 0.01$); for flexion, the left and right sternocleidomastoid fatigued by ~11–14% ($p < 0.01$); for right flexion, the right sternocleidomastoid fatigued by ~15% ($p < 0.01$); for left flexion, the left spenus capitis and left sternocleidomastoid fatigued by ~7.2% ($p = 0.02$) and ~11.2% ($p = 0.03$), respectively; in no trials did the trapezius muscles display fatigue as measured by EMG. Conclusion: The smaller agonist muscles were the most susceptible to fatigue during submaximal isometric endurance movements in the cervical muscles of helicopter aircrew.

INTRODUCTION

The issue of muscular fatigue, particularly in the workplace, and the effects of prolonged postures, repeated movements, or poorly designed workplace ergonomics have frequently been the motivation for published studies.[1,2] Within the helicopter community of global military forces, these factors have been described as causative factors to "a number of occupation ailments" and "these disorders occur primarily in the neck, lumbar, and upper sacral regions."[3] A review of the literature with aircrew-specific publications indicates a growing concern with regard to cervical spinal injuries and pain in the helicopter community that may have a prevalence of between 29 and 90%, depending upon the operational definitions and stratification of results within the individual article.[4–6] Regardless of the exact prevalence, flight-induced neck pain results in lost working days from highly trained aircrew that negatively impacts operational schedules and capabilities.

The military helicopter environment contains specifics likely to induce muscular fatigue within the aircrew. Large-amplitude, low-frequency vibrations are inherent within helicopter flight by design.[7] The mass of the flight helmet plus helmet-mounted devices such as night vision goggles (NVG) can be as much as 3.7 kg and survival equipment can have a mass of approximately 6.4 kg.[8] Average NVG flight duration reported by Canadian aircrew was 2.0 hours/sortie with the length of maximum NVG mission (on average) reported as nearly double that value, i.e., 3.5 hours.[9] Pelham et al.[10] described the typical postures adopted by helicopter aircrew and the resulting detrimental lumbar kyphosis, thoracic kyphosis, and cervical lordosis. While the focus of that article was specific to low back pain, the authors note the "multi-segmental mechanical relationship of the spine" and indicate that the spine does operate as a whole unit. These postures are linked to lengthening and fatiguing of the spinal musculature with a decreased capacity for force development and the nearly constant extension of the cervical spine is thought to result in muscular fatigue of the muscles responsible for maintaining such a position. This would be especially true in an NVG mission because of the additional mass presented by that equipment.

Electromyography (EMG) has been used to monitor workplace activity of the neck muscles in low-load or semistatic environments[11–13] and, more relevant to this article, specifically with military aircrew.[14–16] Largely, EMG has been used to monitor activity during high +Gz maneuvers or during missions with head supported mass such as NVG. We used EMG to evaluate the median frequency response during fatiguing submaximal isometric neck contractions in extension, flexion, and left and right lateral flexion. Similar work has been done with erector spinae in the lumbar spine[17] and the slope of the median frequency as the individual approaches ultimate fatigue has been shown to differentiate those who experience pain from those who do not.[18] However, the EMG related research with military helicopter aircrew and, specifically, the cervical spinal muscles

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have not highlighted which muscle(s) are most likely to fatigue during prolonged cervical spinal force-producing movements and limit an aircrew member's ability to perform that movement under load.[16] In the Canadian forces (CF) helicopter community, this information may prove very important in preventing, mitigating, and rehabilitating the documented epidemic of flight-induced neck strain.[5] Specifically, this information would provide focus for a physical training program to combat flight-induced neck strain within the tactical helicopter community.

Therefore, our purpose was to use EMG in a laboratory setting to evaluate muscle fatigue in the cervical musculature to determine which muscle(s) were most susceptible to fatigue in military helicopter aircrew. Furthermore, we intended to determine which muscle(s), when fatigued, were the primary influence(s) in limiting force production in cervical spinal movements in military helicopter aircrew. We hypothesized the smaller agonistic muscles of each isometric contraction would be most susceptible to fatigue and influence force production by the cervical spine.

METHODS

Subjects

Ethical approval was obtained from the University of Regina's Review of Ethics Board and subjects were provided verbal and written summaries of the goal of the project by both CF personnel and the members of the research team. Forty CF helicopter aircrew (35 M, 5 F; age = 35.3 ± 5.6 years; height = 177.3 ± 8.2 cm; weight = 82.7 ± 11.9 kg) representing all Canadian tactical helicopter squadrons agreed to participate in the study and signed informed consent (Table I). Subject fitness scores were compiled post hoc from the most recent aircrew fitness result on file. This included a step test to predict VO_2max.

Electromyography Monitoring

Six EMG channels, with surface electrodes in a bipolar arrangement, were collected with a commercially available 8-channel system (Bortec Biomedical Ltd., Calgary, Alberta, Canada) over the right and left splenius capitis (SpCR and SpCL), right and left sternocleidomastoid (SCMR and SCML), and right and left upper trapezius (TR and TL) muscles. Placement sites were cleaned with 70% alcohol swab and lightly abraded with fine sandpaper. A reference electrode was affixed over the bony protuberance of C7 and signal quality was visually assessed with custom oscilloscope software (U.S. Army Aeromedical Research Laboratory [USAARL], Fort Rucker, Alabama) through the subject's performance of a series of test movements such as neck flexion/extension and shoulder shrugs.

For each EMG channel during each trial, mean frequency was calculated for every half-second and normalized. Maximum normalized mean frequency values at the start of the endurance trial (Δt_{start} = 15 seconds) for each muscle were calculated. This was then normalized to a value of 1.0. In the final stages of force maintenance during the trial (Δt_{end} = 15 seconds), a maximum normalized mean frequency value was again calculated. Changes in normalized mean frequency were calculated and presented as a percent score.

TABLE I. Summary of Subject Characteristics

Characteristic	Mean ± SD
Sex	35 M; 5 F
Handedness	36 R; 4 L
Age (years)	35.3 ± 5.6
Height (m)	1.77 ± 0.08
Weight (kg)	82.7 ± 11.9
Resting HR (bpm)	68.0 ± 8.6
Resting Systolic BP (mmHg)	114.8 ± 12.5
Resting Diastolic BP (mmHg)	71.8 ± 9.1
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	40.9 ± 5.1
Helicopter Experience (years)	4.9 ± 3.5
Helicopter Experience (hours)	1159.7 ± 945.7
NVG Experience (hours)	136.1 ± 120.4

Isometric Testing

Isometric testing was performed with subjects seated in a standard CH-146 cockpit seat with the appropriate harness tightened and secured to minimize trunk movements during testing. A 5-cm webbing strap was secured around the subject's head and attached to a SSM-AJ-100 force transducer (Interface, Scottsdale, Arizona) that was attached at head level to a 2.5-cm^2 steel pole. The pole could be moved to 4 locations around the seat to allow the subject to perform neck flexion, extension, and left and right lateral flexion contractions.[9,26,27]

Maximal Voluntary Contractions (MVC)

Subjects were instructed to cross their arms on their chest to prevent the generation of additional leverage by grabbing the arm rests of the cockpit chair during isometric contractions. During the MVC testing, subjects were instructed to "gradually ramp" their force up to maximal force production (approximately 2 seconds) to avoid an injury of the neck muscles through a "jerking" movement and the large rate of force development related to those types of movements. Subjects were provided with a practice trial of the extension contraction as this was deemed to be the movement pattern that was least susceptible to fatigue.

MVC testing order was determined randomly prior to the subject's arrival at the laboratory. Each subject performed three 5-second isometric contractions in each direction with a 2-minute rest period between contractions. Following each MVC trial, subjects were asked to provide a rate of perceived exertion (RPE) on a modified (0–10) Borg scale.[19] The MVC trial of the greatest magnitude was saved as the true MVC score and this value was used to calculate the 70% MVC submaximal target forces for endurance testing. Borg RPE values during the MVC phase were averaged to provide an aggregate score.

Endurance

Subjects performed one endurance trial for each of the isometric movements and trial order was again the same as the MVC testing. Target force was 70% of the MVC and subjects were instructed to maintain this force for as long as they could, to a maximum of 180 seconds. Subjects were provided a 5-minute rest period between trials. Subjects were asked to provide a Borg RPE scale[19] value at the completion of each endurance contraction.

Data Analysis

Statistical analysis was performed with SPSS V16.0 (SPSS Inc., Chicago). Paired *t*-tests were used to investigate differences in MVC strength values and times to exhaustion between paired movement directions (i.e., flexion vs. extension or right flexion vs. left flexion) to identify the presence of statistically significant differences or imbalances. Normalized mean frequency values of each endurance trial were analyzed for differences between starting and end peak values using one-way analysis of variance (ANOVA). Differences in RPE values were also investigated with paired *t*-tests. Significance was set at $p < 0.05$.

RESULTS

One-way ANOVA

Extension

Extension MVC was 229.7 ± 50.6 Newtons (N) and the RPE was 8.4 ± 1.5. Time to exhaustion for the endurance trial was 55.6 ± 34.5 seconds and the associated RPE was 9.0 ± 1.2. The SpCR and SpCL muscles were the only muscles to exhibit a statistically significant change in normalized mean frequency (left $p < 0.01$; right $p < 0.01$) (Fig. 1). The mean decrease in normalized mean frequency in left and right normalized mean frequency was 21.2 ± 22.6% and 22.5 ± 18.1%, respectively.

Flexion

Flexion MVC was 169.6 ± 44.5 N with an RPE value of 8.2 ± 1.3. Time to exhaustion was 40.6 ± 15.6 seconds and the reported RPE was 8.9 ± 1.2. Significant differences in start and end normalized mean frequencies for the SCMR, SCML, TR, and TL muscles were observed (Fig. 2). The SCMR ($p < 0.01$) and SCML ($p < 0.01$) muscles displayed significant decreases in normalized mean frequencies (left 14.8 ± 18.3%; right 11.5 ± 16.0%), indicative of fatigue. The trapezius muscles, TR ($p < 0.01$) and TL ($p < 0.01$), displayed increases in normalized mean frequencies (TR 94.1 ± 145.6%; TL 119.9 ± 142.6%), indicative of increased activity.

Right Flexion

Right flexion MVC was 176.8 ± 43.9 N with an RPE of 8.4 ± 1.4. Time to exhaustion for the submaximal endurance trial was 62.4 ± 31.2 seconds and the associated RPE was 8.4 ± 1.4. Only the SCMR displayed a significant change ($p < 0.01$) in normalized mean EMG frequency during the submaximal endurance trial (Fig. 3). The normalized mean EMG frequency for the SCMR decreased (14.7 ± 15.7%).

Left Flexion

Left flexion MVC was 186.1 ± 43.3 N and the RPE was 8.6 ± 1.4. Time to exhaustion for the submaximal endurance trial was 65.3 ± 33.5 seconds and subjects reported an RPE of 8.9 ± 1.3. The prime agonists, the SpCL (7.3 ± 29.5%) and the SCML (11.2 ± 13.2%), both demonstrated statistically significant decreases in normalized mean EMG frequency ($p < 0.05$) (Fig. 4).

Paired t-Tests Between Isometric Movements

Flexion vs. Extension

Extension MVC values were significantly greater than flexion MVC values for the 40 subjects ($p < 0.01$). Additionally, time to fatigue for the extension isometric movement was significantly greater than time to fatigue for the flexion isometric movement ($p < 0.01$). No statistical difference was found in RPE scores for MVC values ($p = 0.11$) or for endurance trials ($p = 0.65$).

Right vs. Left Flexion

Left flexion MVC values were significantly greater than right flexion MVC values for the 40 subjects ($p < 0.01$). However, no statistical difference was found between time to exhaus-

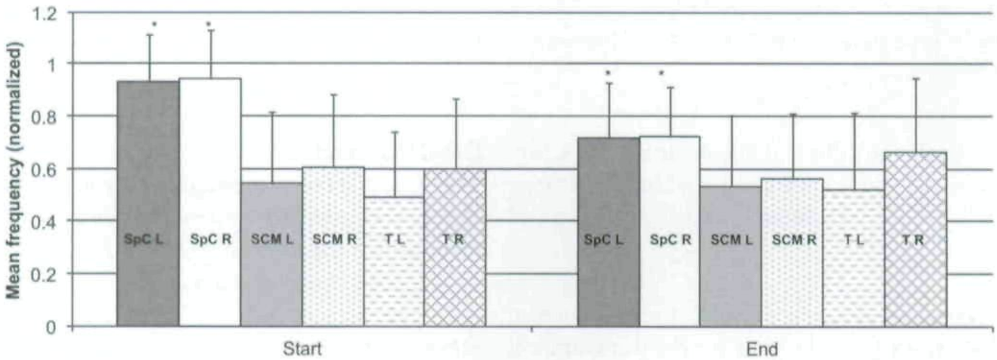

FIGURE 1. Changes in normalized mean EMG frequency of cervical muscles during isometric extension submaximal endurance trial (* denotes significant differences; $p < 0.05$).

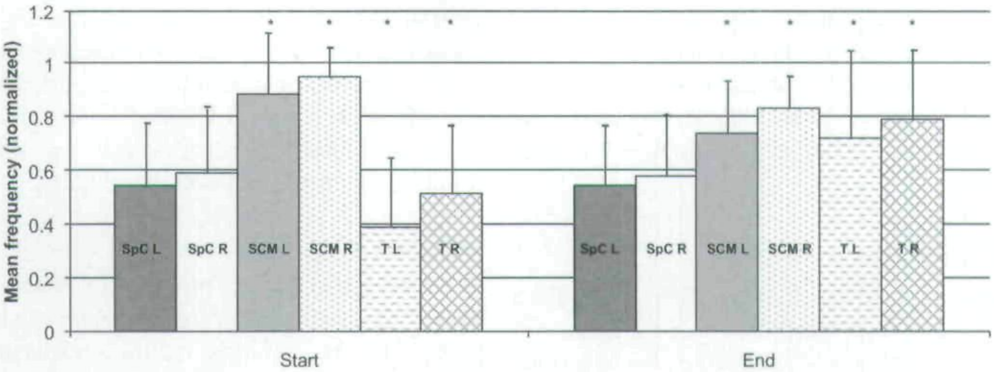

FIGURE 2. Changes in normalized mean EMG frequency of cervical muscles during isometric flexion submaximal endurance trial (* denotes significant differences; $p < 0.05$).

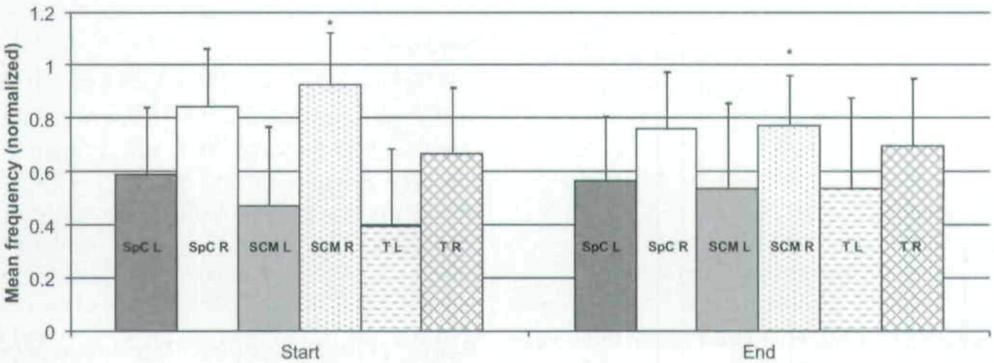

FIGURE 3. Changes in normalized mean EMG frequency of cervical muscles during isometric right flexion submaximal endurance trial (* denotes significant differences; $p < 0.05$).

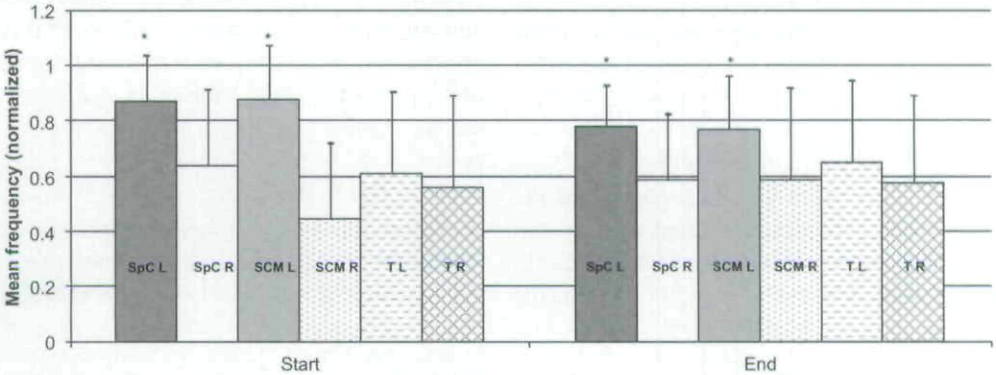

FIGURE 4. Changes in normalized mean EMG frequency of cervical muscles during isometric left flexion submaximal endurance trial (* denotes significant differences; $p < 0.05$).

tion for the fatigue trials for right and left flexion ($p = 0.26$). Furthermore, no statistical difference was found in RPE scores for the MVC ($p = 0.70$) or for endurance trials ($p = 0.81$).

RPE

No statistically significant differences were found between RPE for the 4 MVC trials ($p = 0.81$) or for the 4 endurance trials ($p = 0.92$). Reported values do indicate a maximal effort for all trials.

DISCUSSION

This study showed normalized mean frequency in an EMG signal, collected during an endurance trial, to be an effective method of measuring neuromuscular fatigue in the cervical muscles of helicopter aircrew. The use of bilateral EMG monitoring of the splenius capitis, sternocleidomastoid, and upper trapezius during the endurance trial has provided insight into which muscles, particularly smaller agonists, fatigue to a greater degree as compared to other agonist muscles. This was observed to occur simultaneously to the inability to maintain force that was, relative to MVC results, identical for each of the 40 subjects. This insight will be of benefit to those responsible for the design of fitness or rehabilitation programs for aircrew members who may develop or have already developed neck pain related to flight.

The duration and nature of our submaximal endurance test was the result of collaboration with researchers at the United States Army Aeromedical Research Laboratory and through modification, as per the author's discussion in his article, of Thuresson's testing protocol.[16] Neuromuscular fatigue was not observed in the upper trapezius during the endurance trials. The trapezius was the largest of the muscles monitored during this protocol and it would seem logical that the smaller muscles (splenius capitis or sternocleidomastoid) would be first to fatigue, particularly during extension or lateral flexion trials. The development of fitness programs to improve strength and endurance of the cervical muscles in helicopter aircrew should, according to our results, consider a focus on these smaller cervical muscles.

Previous studies to improve neck and shoulder function among neck pain sufferers, while including neck-specific training, have also specifically targeted the trapezius muscles and sometimes other large muscles of the body, and/or the associated strength capacities of those muscles.[20–23] Although "exercise interventions are deemed essential for the effective management of patients with neck pain,"[1] the current methods of improving strength and inducing hypertrophy may not provide benefits that transfer to the aircrew population (although this remains to be tested with a well-controlled and -designed training program; see discussion below). The MVC results exceeded the force requirements of the cervical musculature dictated by head mounted equipment masses and the forces they produce in a low +Gz operating environment.[8] Furthermore, at no point in testing did trapezius function decrease significantly during any trial. This difference in behavior in trapezius muscles as compared to splenius capitis and sternocleidomastoid muscles is consistent with other findings from isometric testing protocols.[12] Therefore, it would seem appropriate to target the muscles displaying fatigue over the course of the endurance trials as it would appear that the onset of fatigue in these muscles had a negative impact on force maintenance during the trial. That is, for extension, both the left and right splenius capitis muscles should be targeted; for flexion, the left and right sternocleidomastoid muscles should be the focus; coincidentally, the targeting of these muscles for extension and flexion movements will address the needs of lateral flexion trials.

As for whether strength or endurance capacities of the neck musculature should be the focus of a training intervention for aircrew, some provisional conclusions can be drawn from our results. Compared to a healthy nonmilitary population, our aircrew population exhibited greater MVC isometric strength results.[24] Compared to Ang et al.'s[14] work with military pilots, reporting both neck pain and healthy data, our aircrew's MVC results, when converted to force (N) from work (Nm) by estimation, appear to have been much higher than their reported flexion and extension results. Furthermore, 18 (45%) of our subjects did report neck pain that was either mild or very mild at the time of testing. These subjects provided average MVC results that were greater than those averages reported by Ang et al.[14] for either the healthy control or the neck pain group of helicopter pilots. In fact, the individual reporting the greatest neck pain in our study performed an extension MVC of 297.1 N and a flexion MVC of 200.9 Nm, compared to a population average extension of 229.7 ± 50.6 N and a population average flexion of 169.6 ± 44.5 N. This would suggest an increase in strength alone of the cervical musculature to be insufficient to fully address the issue of neck pain.

Analysis of a helicopter aircrews' working environment would lend further support to incorporating an element of muscular endurance to any neck-related training program to prevent or rehabilitate flight-induced neck pain. As reported by Weirstra,[8] the forces experienced by a helicopter aircrew member are far less in magnitude as compared to the forces produced during the MVC trials. Even when the +Gz forces experienced by military helicopter aircrew are considered, the forces produced during the MVC trials by our subjects are still much greater in magnitude than those experienced at the neck during flight. Therefore, if any improvement in muscular performance would benefit the aircrew, our data would suggest that it might be the endurance component. Although this approach may have benefit with respect to other aircrew, such as fixed wing (fast jet or transport) aircrew communities, this should be a focus of scientific investigation before becoming accepted as common practice. Numerous studies[5–8,10] have described the aspects of the working environment that distinguish it from the various fixed wing communities. Other studies[6,14] provide some evidence of differences with respect to potential mechanisms of injury—these authors have hypothesized the mechanism in helicopter aicrew to be insidious whereas the fixed wing aircrew may become injured as a result of an acute event stemming from increased +Gz forces.

Only one side difference was found to be significant following the statistical analyses. The MVC result for left lateral flexion was significantly greater than the MVC result for right lateral flexion. The times to exhaustion and the normalized EMG results did not provide any evidence of a left or right deficit. However, the MVC result was used to determine the workload for the submaximal endurance trials. Therefore, it would appear that this deficit was present in the submaximal endurance trials because the right side did not perform longer during the lateral flexion trials as compared to the left despite having a lower calculated workload (i.e., 70% of the right MVC would be less than 70% of the left MVC).

The greater strength on the left side was a surprise finding. Subjects were primarily right-handed. Society is primarily right-handed in terms of interacting with technology and everyday items. It would seem logical to expect that right lateral flexion MVC would be greater than the left lateral flexion

MVC. However, this was not the case and the literature does provide a potential explanation. Previous work with spinal musculature EMG in helicopter pilots reported greater rates of activation on the right side of the spine in the lumbar spinal muscles.[25] Our work in a flight simulator with helicopter pilots in which the trapezius muscles were monitored with near infrared spectroscopy (NIRS) did also note greater metabolic activity (i.e., muscle oxygenation and blood volume) on the right side during day missions and night missions in which the added mass of the night vision goggles was present.[9,26,27] Therefore, while it might seem logical to expect a predominantly right-handed population of regular members of society to demonstrate greater strength in the musculature of the right side of their body, this may be another factor that does not transfer to a helicopter aircrew population. The members of the helicopter aircrew population may be experiencing some level of sustained fatigue in the musculature on the right of the spinal column as a result of their duties and job demands. We hope that these results may influence the design of appropriate training programs to address this issue in the near future.

Such a training study has recently been completed by our research group, with the publication of the results in the peer review anticipated in the very near future.[28] The results indicate that a program with the appropriate focus on muscular endurance, particularly exercises designed to focus upon the deep postural muscles of the cervical spine, does have a positive impact upon the performance of the submaximal protocol described in this article. Whether this translates into benefits with respect to job performance in the long term has yet to be established. However, on a case report level, the work by Salmon[28] did provide what individual subjects, who had previously been removed from flight duties because of spinal pain, described as significant improvements in daily functioning.

CONCLUSION

Normalized mean EMG frequency of cervical neck musculature during submaximal isometric endurance contractions can be used in helicopter aircrew to identify those muscles that fatigue quickest and effect force production and maintenance. This approach will benefit the application and assessment of muscular training programs to prevent and rehabilitate flight-induced neck pain among this population.

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