Neck and Shoulder Muscle Activation Among Experienced and Inexperienced Pilots in $+G_z$ Exposure

Tuomas Honkanen; Juha Oksa; Matti J. Mäntysaari; Heikki Kyröläinen; Janne Avela

BACKGROUND: The aim of the present study was to compare differences in electromyography (EMG) activation of the neck and shoulder muscles between groups of inexperienced and experienced pilots during controlled $+G_z$ exposure in a centrifuge.

METHODS: The subjects were volunteer cadets (inexperienced group) and lieutenants (experienced group) undergoing their first centrifuge training. The first group did not have any high performance aircraft (HPA) experience, while the latter one had a 1-yr experience of intense flying of HPA. During the centrifuge run, EMG activity was recorded from the left and right shoulder, neck flexor, and neck extensor muscles.

RESULTS: The pilots without HPA experience had significantly higher muscle activity in the neck flexor and extensor muscles during the last 5 s of the recorded period at G levels exceeding +7.4.

DISCUSSION: Muscle activity in the neck and shoulder muscles was gradually higher among the whole study group with increasing $+G_z$ forces. Because pilots without any HPA experience had significantly higher muscle activity than their counterparts with experience of HPA, we suppose that the experience of high $+G_z$ forces might lead to lower muscle activation in the same flight mission.

KEYWORDS: cervical spine, electromyography, high performance aircraft, G force.

Honkanen T, Oksa J, Mäntysaari MJ, Kyröläinen H, Avela J. *Neck and shoulder muscle activation among experienced and inexperienced pilots in +Gz exposure.* Aerosp Med Hum Perform. 2017; 88(2):90–95.

The prevalence of neck pain among fighter pilots[14] is high compared to the general population[4] and pilots flying high performance aircraft (HPA) report a higher rate of flight-related neck injuries than pilots flying other fixed wing carriers.[8,19] The exposure to high $+G_z$ acceleration while flying HPA is known to cause high static muscle stress in the neck muscles.[7,12]

Pilots flying modern HPA are constantly exposed to high $+G_z$ forces. Approximately 20% of the flying time during air combat is spent above +2 G_z while the peak levels can range from +7 G_z to +9 G_z.[9] It has been reported that muscular strain increases in line with increasing G forces.[7,12] According to the study of Hämäläinen and Vanharanta,[7] the mean electromyography (EMG) activity of the neck extensor muscles, without head movements, is 6, 16, and 38% of maximal voluntary contraction (MVC) at +1, +4, and +7 G_z levels, respectively.

When in-flight neck flexor muscle activity has been compared between thigh, abdominal, and back muscles, it has been shown that EMG activity levels remain mainly below 10% of MVC in other muscle groups except the neck muscles.[12] There are, however, more episodes (lasting ≥1 s) exceeding 50% of EMG activity of the corresponding MVC in the neck muscles than other studied muscle groups.[12] Both of these findings were reported from a one-to-one aerial combat maneuvering exercise, where the mean in-flight G level exceeded +5 G_z for 4 min 46 s and the +7 G_z level for 48 s. It has also been found out that more experienced pilots contract their muscles more synchronously during anti-G straining maneuvers (AGSM), which has led to a conclusion that the AGSM of inexperienced pilots might not be as effective as the AGSM of experienced pilots.[12]

Cervical loading in the high G environment has been studied with EMG recordings quite extensively. Depending on the study, high G environments have been created either with

From the Department of Biology of Physical Activity, University of Jyväskylä, Finland, and the Aeromedical Centre, Centre for Military Medicine, the Finnish Defence Forces, Helsinki, Finland.

This manuscript was received for review in May 2016. It was accepted for publication in November 2016.

Address correspondence to: Tuomas Honkanen, P.O. Box 50, FI-00301 Helsinki, Finland; tuomas.honkanen@mil.fi.

DOI: https://doi.org/10.3357/AMHP.4659.2017

trampoline,[16,17] centrifuge,[1] or with a real fighter aircraft.[6,7] The studies[11,13] that are executed in the centrifuge or in flight have had small numbers of subjects (ranging from 2–10). The studies[16,17] with bigger numbers ($N = 14$) of subjects done with trampoline bouncing had the limitation of $+G_z$ exposure ($+4\ G_z$ at maximum), which is relatively low compared to peak $+G_z$ levels in flying. As far as we know, there are no studies with more than 10 subjects that concentrated on defining the EMG levels of neck muscles in the centrifuge, where the G_z level is up to $+8\ G_z$.

The purpose of the present study was to compare differences in EMG activations between groups of inexperienced and experienced pilots. We hypothesized that pilots without any HPA experience would have higher muscle activities than their counterparts with 1 yr of experience of HPA.

METHODS

Subjects

The study population consisted of 29 Finnish Air Force (FINAF) pilots, who volunteered for the present study. There were 15 FINAF lieutenants with 1 yr of experience of HPA (experienced) and 14 FINAF Air Force Academy cadets without any HPA flying history (inexperienced). The group of experienced pilots had been flying Hawk Mk 51 Jet trainers capable of a maximum of $+8\ G_z$, while the group of inexperienced pilots had experience of flying only with early trainers (Valmet L-70 Vinka, four-cylinder piston-engine propeller planes, not exceeding $+4\ G_z$). The Ethics Committee of the National Defense University approved this study.

The mean ($\pm$ SD) age, body mass, height, and strength test results of the inexperienced and experienced pilots are presented in **Table I**. There was no statistically significant difference in anthropometry between these groups. None of the subjects had a history of any spinal complaints nor did the group of the experienced pilots have any flight-related musculoskeletal symptoms. The physical tasks and amount of sleep were standardized and controlled in both groups 3 d prior to a test run. Two subjects (one from each group) were excluded from the analysis due to technical problems (disconnected cable) in EMG measurements before analyzing the data.

The background information was gathered with a self-administrated questionnaire (conducted after the test run in the centrifuge) and from the database of the Kuortane Sports Institute, where pilots' physical fitness had been tested 6 mo before centrifuge training. The questionnaire included information on previous neck pain episodes, physical activity level, and usage of tobacco products. In addition, self-rated quality of sleep as well as more profound questions about level of physical activity in the last 3 d before centrifuge testing were asked. The physical tests included the standard FINAF fitness test: maximal isometric strength tests (lower limbs, trunk flexors and extensors) and dynamic muscle tests (sit-ups and seated dumbbell press). All physical tests were done as a part of the FINAF regular and annual testing, not just organized for this study, and the results were collected from the database. There were no statistical differences in physical fitness test results between the inexperienced and experienced groups (Table I).

Equipment

The $+G_z$ exposure was done in a modern dynamic flight simulator centrifuge (Wyle Laboratories Inc., El Segundo, CA) in Linköping, Sweden. The centrifuge has a 9.14-m radius and is capable of a maximum force of $+15\ G_z$ with acceleration up to $+10\ G \cdot s^{-1}$. The two-degrees of freedom gondola's system is based on the JAS 39 Gripen (Saab Ltd., Linköping, Sweden) aircraft controls. The seat of the gondola is a Martin-Baker ejection seat (Martin-Baker Aircraft Co. Ltd., Middlesex, UK), which is used in a real aircraft. The seatback angle is 28°. EMG was recorded from a standardized gradual onset (GO), where each subject was supposed to pull total of $+8\ G_z$ with an onset rate of $+0.1\ G_z \cdot s^{-1}$.

Muscle activity was recorded with surface EMG. The EMG was measured using a portable EMG device (ME6000, Muscle tester, Mega Electoronics Ltd., Kuopio, Finland). Use of this equipment has been found reliable for measuring neck and shoulder muscle activity,[18] and a device from the same manufacturer has been used in several previous studies.[1,12,16]

Table I. Comparison Between Demographic Information and Strength Test Results Among Experienced and Inexperienced Pilots.

DEPENDENT VARIABLES	NONEXPERIENCED	EXPERIENCED	*P-VALUE*
Demographics			
Age (yr)	22.3 ± 0.6	23.0 ± 0.4	0.006
Mass (kg)	77.6 ± 6.7	75.6 ± 9.7	0.204
Height (cm)	180.3 ± 2.9	178.4 ± 5.8	0.904
BMI (kg/m^2)	23.9 ± 2.2	23.7 ± 2.4	0.241
Isometric maximal strength tests			
Abdominal (kg)	83.5 ± 14.3	73.8 ± 13.3	0.816
Back (kg)	116.2 ± 20.5	110.6 ± 19.4	0.799
Leg extensor (kg)	227.7 ± 45.9	251.3 ± 61.0	0.204
Dynamic tests			
Dumbbell raise (reps/min)	76 ± 22	66 ± 15	0.127
Modified sit-up (reps/min)	46 ± 12	48 ± 10	0.280

BMI = body mass index.

Procedure

The electrode placement was done according to the recommendations of Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM), the concerted action in the Biomedical Health and Research Program of the European Union.[5] During the centrifuge run, the EMG activities were recorded from six sites: right and left sternocleidomastoid (SCM), right and left trapezius (TRA), and right and left cervical (CES) erector spinae muscles. The bipolar surface electrodes were placed on the SCM bilaterally over the SCM muscle belly, and, respectively, on the CES over the splenius capitis muscle. For the TRA measurements, the electrodes were placed over the anterolateral margin midway between the acromion and occiput. The electrode positions used were in line with previous EMG studies[1,2,16] among fighter pilot populations. The preparation before applying the electrodes included: shaving, sandpapering, and cleaning the skin. The electrodes used in this study were Norotrode™ Dual electrodes (Myotronics, Inc., Kent, WA) with an interelectrode distance of 22 ± 1 mm. Measured signals were preamplified 1000 times. The signal band varied between 20 and 500 Hz, and it was full-wave rectified and averaged with a 100-ms time constant during the whole exposure.

The recorded EMGs in the centrifuge were normalized to EMGs recorded during isometric MVC. The MVC testing was done prior entering the centrifuge with the same electrodes and their placements. MVC was performed as isometric contractions for cervical flexion (for SCM), shoulder rise (for TRA), and cervical extension (for CES). The results in this study are expressed as the percent of the maximal voluntary contraction of the measured muscle (% MVC). Each subject was tested after mandatory and controlled warm-up procedures and each subject was instructed to push maximally for 3 s with strong verbal encouragement. Each muscle group was separately tested three times with a 1-min rest between the tests and the best performance according to the highest force value was taken into further analysis.

After the subjects positioned themselves in the gondola, the centrifuge started to idle at +1.4 G_z. The standardized GO was done before any other +G_z exposure on the same day. The total time of the measured exposure was (from +1.4 G_z idle to +8.0 G_z) 66 s. The subjects did not wear helmets due to the centrifuge training regulations of FINAF and they were instructed to avoid unnecessary head movements for safety reasons. There were two subjects from the inexperienced group and one from the experienced group who did not succeed in pulling the maximum +8.0 G_z. These three subjects stopped their gradual onset at +7.0 G_z due to severe arm pain. The passive G tolerance (PGT), which was determined by the centrifuge instructor, was measured in both groups. It is individual at which G_z level a pilot starts AGSM (due to tunnel vision) during standardized GO. Every pilot of the present study had the same experience of centrifuge runs (two prior to the test run) before the measurement. Respectively, every pilot had the same anti-G straining maneuver training with the same instructors.

Statistical Analysis

The Student's *t*-test was used for comparison between demographic information and strength test results among the experienced and nonexperienced pilots (Table I) as well as comparison between passive G tolerances. Respectively, we used the Student's *t*-test to compare the statistical difference between levels of the measured variables (EMG) between the two groups in each measurement point separately. The level of significance was set at 0.05.

RESULTS

Fig. 1 demonstrates that EMG activity increases with increasing G_z. The mean activity increased in all measured muscles with both the experienced and inexperienced groups. The mean activity of the measured muscles for both groups is presented in **Table II**. The pilots without HPA experience had significantly higher muscle activities in the sternocleidomastoid of the neck flexor muscles ($F = 4.8$, df = 23, $P = 0.04$)

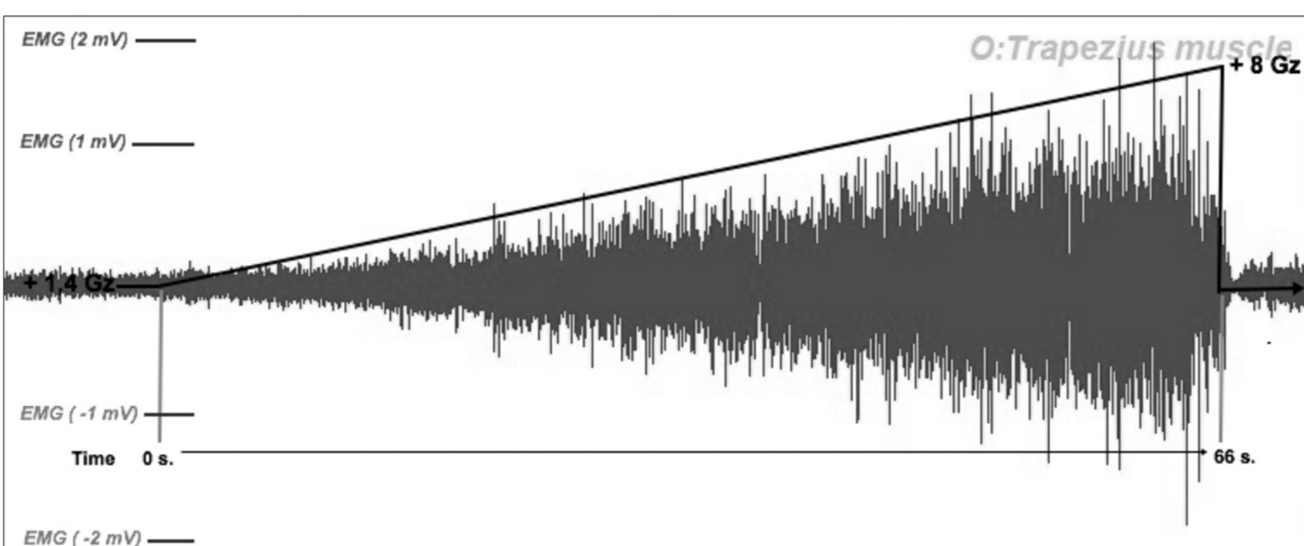

Fig. 1. A representative example of a raw EMG signal of the right trapezius muscle and the respective increase of +G_z forces as a function of time.

Table II. The Mean (± SD) EMG (% max) of the Measured Muscles.

TIME (s)	0–5	15–20	30–35	45–50	60–65†
$+G_Z$ LEVEL	1.4–1.9	2.9–3.4	4.4–4.9	5.9–6.4	7.4–7.9
Sternocleidomastoid, L (IE)	1.4 (± 0.5)	3.8 (± 2.8)	9.1 (± 7.7)	20.2 (± 12.5)	30.0 (± 13.4)*
Sternocleidomastoid, L (Exp)	1.3 (± 0.5)	2.9 (± 2.0)	5.6 (± 3.1)	17.5 (± 7.4)	20.4 (± 7.8)*
Sternocleidomastoid, R (IE)	2.0 (± 3.2)	3.3 (± 5.8)	6.7 (± 9.5)	18.0 (± 17.5)	29.0 (± 28.7)
Sternocleidomastoid, R (Exp)	1.1 (± 0.6)	2.0 (± 1.3)	4.9 (± 3.1)	16.9 (± 11.9)	22.7 (± 17.5)
Erector spinae, L (IE)	4.5 (± 2.2)	9.0 (± 5.4)	17.0 (± 9.0)	34.0 (± 18.4)	49.2 (± 27.6)*
Erector spinae, L (Exp)	4.2 (± 2.7)	8.4 (± 5.4)	15.0 (± 9.9)	30.6 (± 13.7)	31.5 (± 10.0)*
Erector spinae, R (IE)	3.7 (± 2.1)	7.7 (± 4.9)	14.8 (± 7.3)	30.2 (± 14.4)	42.1 (± 21.3)
Erector spinae, R (Exp)	4.5 (± 3.2)	8.5 (± 5.6)	15.5 (± 9.3)	32.5 (± 15.8)	33.9 (± 12.8)
Trapezius, L (IE)	3.9 (± 3.5)	9.4 (± 6.8)	18.8 (± 22.5)	30.6 (± 39.5)	35.0 (± 39.2)
Trapezius, L (Exp)	2.9 (± 2.9)	7.5 (± 4.7)	11.8 (± 4.8)	23.1 (± 11.0)	25.8 (± 39.2)
Trapezius, R (IE)	1.9 (± 2.5)	7.2 (± 8.4)	12.5 (± 11.4)	20.2 (± 17.2)	32.2 (± 21.8)
Trapezius, R (Exp)	3.8 (± 5.1)	9.5 (± 8.0)	16.4 (± 10.7)	24.9 (± 16.9)	25.9 (± 21.8)

L = left side, R = right side, IE = inexperienced pilots, Exp = experienced pilots.
†One subject in each group did not increase the level to >7.0 $+G_Z$; *indicates significance.

and the erector spinae of the neck extensor muscles ($F = 4.7$, df = 23, $P = 0.04$) on the left side during the last 5 s of the recorded period at G levels exceeding +7.4. The respective results from the recordings taken from the trapezius muscle were also higher among the pilots without HPA experience (Table II), but this difference was not statistically significant between the groups.

The combined (left and right side) mean EMG % was significantly higher among the pilots without HPA experience. The combined mean EMG % was 29.5% (± 29.0) in the sternocleidomastoid muscles and 45.7% (24.7) in the erector spinae muscles among the inexperienced and, respectively, it was 21.6% (± 12.7) and 32.7% (± 11.4) among the experienced pilots (**Fig. 2**). There was one subject in both groups who could not reach 65 s of GO.

The PGT was significantly ($F = 6.5$, df = 24, $P = 0.018$) higher among pilots with HPA experience. The mean level of PGT among inexperienced and experienced pilots was +4.6 G_z (± 0.6) and +5.0 G_z, (± 0.2), respectively (**Fig. 3**). There was no association between AGSM starting time and any muscle activity.

DISCUSSION

The main finding of the present study was that experienced pilots had less muscle activity during +7.4–+7.9 G_z than their inexperienced counterparts. When these results were compared to the study of Ang[1] done in the same centrifuge, higher relative EMG activities in the neck flexor (sternocleidomastoid) and extensor (splenius capitis) muscles were observed even without a helmet in the present study. One explanation for the difference between the results could be that in Ang's[1] study, only very experienced senior test pilots with mean flight experience (flight hours) of 2570 h participated. When our results are compared to previous in-flight studies,[11,12] it can be seen that peak values are much higher in the real aircraft, where over 50% of MVC peak values are common. This was predictable because of the lack of head maneuvering and helmet weight in our present study.

Furthermore, we could accept our hypothesis that pilots without any HPA experience would have higher muscle activities in the neck flexor and extensor muscles, but only at the highest $+G_z$ forces. When muscle activity was compared to

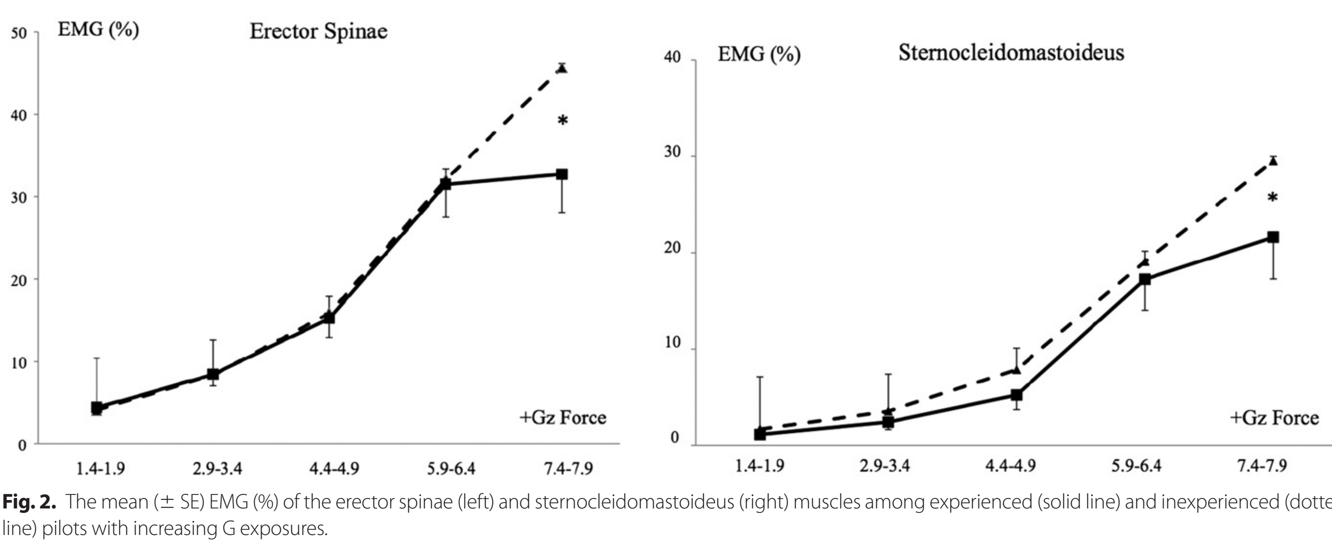

Fig. 2. The mean (± SE) EMG (%) of the erector spinae (left) and sternocleidomastoideus (right) muscles among experienced (solid line) and inexperienced (dotted line) pilots with increasing G exposures.

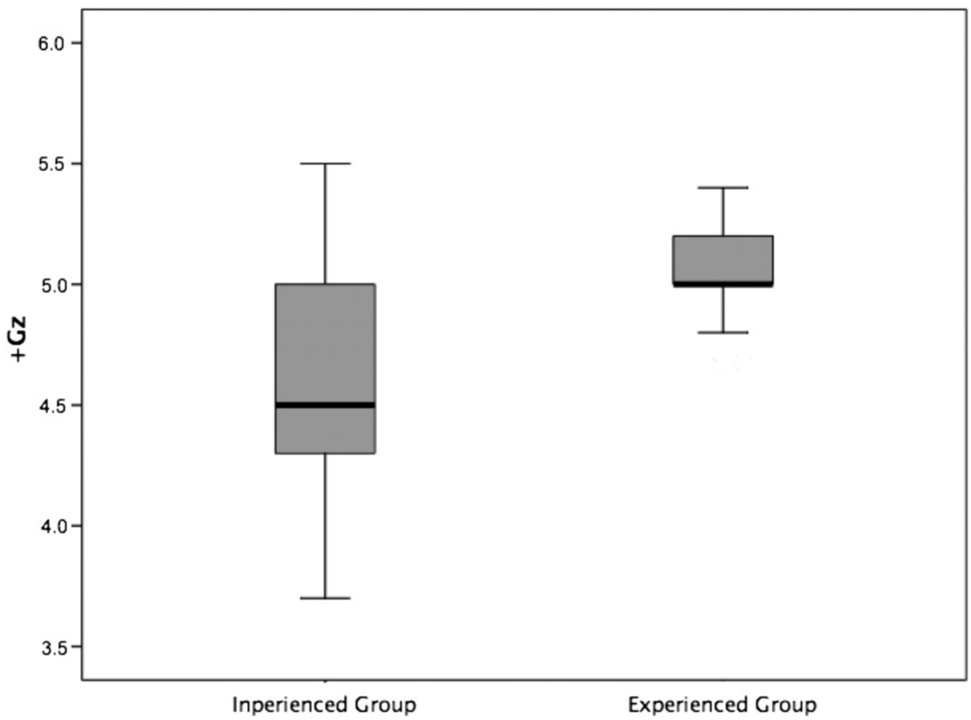

Fig. 3. The mean (± SE) passive G tolerance between the groups.

individual AGSM, it was not related to the starting time of AGSM. Interestingly, the passive G tolerance (the time when AGSM was started) was 0.4 G_z less with inexperienced pilots. That finding might be due to G tolerance adjusted beforehand or courage due to experience to start AGSM later. Measuring passive G tolerance was not part of our aim, but rather an incidental output which we were able to gather from the instructors' records. Nevertheless, we think that time of AGSM is related to physical loading of HPA pilots and, therefore, worth publishing among our other findings.

We point out that flight duty itself might be more demanding and cause more muscle fatigue to less experienced pilots due to longer AGSMs and higher muscle activity. The present sample is representative of the FINAF pilot community of the ages between 22–25 yr. Both groups were similar in demographics and physical fitness to FINAF pilot. In addition to that, both groups had exactly the same AGSM training with the same instructors and similar experience of centrifuge runs (two runs on previous days on the same week as testing GO was performed). Because the only difference between the groups was experience of flying HPA, we consider the results to be applicable to the whole FINAF pilot community.

When examining the results of the present study, it should be considered that our subjects did not wear helmets due to centrifuge training regulations of FINAF. The helmet weight alone has been reported to increase muscle activity in the cervical muscles in a high $+G_z$ environment,[13] while using lighter helmets has been reported to reduce mean muscular activity from the cervical muscles.[6] When night-vision goggles are added to a standard helmet, it appears to cause even greater neck muscle activity due to increased loading.[1,16] According to these studies, it can be assumed that a helmet would have increased muscle activity.

In addition to the absence of the helmet, the absence of large head movements have to be taken into account when examining the present (EMG) activity levels and comparing them to in-flight studies. In the present study, we consciously missed the opportunity to measure the effect of head movement to ensure the safety of our subjects. In the neutral position, the cervical spine is capable of supporting large external loads and, thus, spinal injuries in the centrifuge (while the head is in its neutral orientation) are rare. In real aircraft, the common "check six" (observing behind the aircraft) procedure requires rotation accompanied by extension, which are both beyond the limit of high-risk movements[10] which have well been described in the literature.[3,15] Those movements include: rotations exceeding 35°, extensions exceeding 30°, and flexions exceeding 15°. Thus muscular activity in the cervical muscles increases with both increasing of $+G_z$ forces and head movements.[7]

Besides the absence of flight helmets, the simulation setup of the present study may be considered as close to real aircraft flight as possible, including real aircraft hardware such as a Martin-Baker ejection seat as well as a realistic stick and throttle. The lack of head movements and helmet weight makes comparison to other studies difficult. However, this does not affect the results of the present study, when the other aim, comparing the muscle activity between experienced and inexperienced pilots, is examined.

For further studies, these test pilots will be followed in order to find out the relationship between neck muscle MVC and possible later flight-related neck symptoms. It has been shown that fighter pilots with neck pain have a significantly lower neck extensor muscle MVC than their counterparts without neck pain.[2] Yet it has not been established whether the pain causes lower muscular activity or vice versa and the predictive role of higher MVC in the neck muscles is uncertain.

In conclusion, the results of the present study indicate that muscle activities in the neck and shoulder muscles are relatively high when increasing $+G_z$ forces even without the additional weight of the helmet and even the head when it is in its neutral orientation. In this study sample, the pilots without any HPA experience had significantly higher muscle activity (at over $+7.4\ G_z$) and, thus, lower passive G tolerance than their counterparts who had experience of HPA. Therefore, the same flight mission with $+G_z$ exposure could be more fatiguing with less HPA experience.

ACKNOWLEDGMENTS

Authors and affiliations: Tuomas Honkanen, M.Sc., and Matti J. Mäntysaari, M.D., Ph.D., Aeromedical Centre, Centre for Military Medicine, The Finnish Defense Forces, Helsinki, Finland; Juha Oksa, Ph.D., Finnish Institute of Occupational Health, Oulu, Finland; and Heikki Kyröläinen, Ph.D., and Janne Avela, Ph.D., Department of Biology of Physical Activity, University of Jyväskylä, Finland.

REFERENCES

1. Ang BO, Kristoffersson M. Neck muscle activity in fighter pilots wearing night-vision equipment during simulated flight. Aviat Space Environ Med. 2013; 84(2):125–133.
2. 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; 76(4):375–380.
3. Coakwell MR, Bloswick DS, Moser R Jr. High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviat Space Environ Med. 2004; 75(1):68–80.
4. Fejer R, Kyvik KO, Hartvigsen J. The prevalence of neck pain in the world population: a systematic critical review of the literature. Eur Spine J. 2006; 15(6):834–848.
5. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol. 2000; 10(5):361–374.
6. Hämäläinen O. Flight helmet weight, +Gz forces, and neck muscle strain. Aviat Space Environ Med. 1993; 64(1):55–57.
7. Hämäläinen O, Vanharanta H. Effect of Gz forces and head movements on cervical erector spinae muscle strain. Aviat Space Environ Med. 1992; 63(8):709–716.
8. Knudson R, McMillan D, Doucette D, Seidel M. A comparative study of G-induced neck injury in pilots of the F/A-18, A-7, and A-4. Aviat Space Environ Med. 1988; 59(8):758–760.
9. Newman DG, Callister R. Analysis of the Gz environment during air combat maneuvering in the F/A-18 fighter aircraft. Aviat Space Environ Med. 1999; 70(4):310–315.
10. Newman DG. +Gz-induced neck injuries in Royal Australian Air Force fighter pilots. Aviat Space Environ Med. 1997; 68(6): 520–524.
11. Oksa J, Hämäläinen O, Rissanen S, Salminen M, Kuronen P. Muscle fatigue caused by repeated aerial combat maneuvering exercises. Aviat Space Environ Med. 1999; 70(6):556–560.
12. Oksa J, Hämäläinen O, Rissanen S, Myllyniemi J, Kuronen P. Muscle strain during aerial combat maneuvering exercise. Aviat Space Environ Med. 1996; 67(12):1138–1143.
13. Phillips CA, Petrofsky JS. Neck muscle loading and fatigue: systematic variation of headgear weight and center-of-gravity. Aviat Space Environ Med. 1983; 54(10):901–905.
14. Shiri R, Frilander H, Sainio M, Karvala K, Sovelius R, et al. Cervical and lumbar pain and radiological degeneration among fighter pilots: a systematic review and meta-analysis. Occup Environ Med. 2015; 72(2):145–150.
15. Snijders CJ, Hoek van Dijke GA, Roosch ER. A biomechanical model for the analysis of the cervical spine in static postures. J Biomech. 1991; 24(9):783–792.
16. Sovelius R, Oksa J, Rintala H, Huhtala H, Siitonen S. Neck muscle strain when wearing helmet and NVG during acceleration on a trampoline. Aviat Space Environ Med. 2008; 79(2):112–116.
17. Sovelius R, Oksa J, Rintala H, Huhtala H, Siitonen S. Ambient temperature and neck EMG with +Gz loading on a trampoline. Aviat Space Environ Med. 2007; 78(6):574–578.
18. 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; 15(3):323–331.
19. Vanderbeek RD. Period prevalence of acute neck injury in U.S. Air Force pilots exposed to high G forces. Aviat Space Environ Med. 1988; 59(12):1176–1180.