Neck Muscle Strain in Air Force Pilots Wearing Night Vision Goggles

Magnus Wallquist Pousette; Riccardo Lo Martire; Jan Linder; Mats Kristoffersson; Björn O. Äng

INTRODUCTION: Flight-induced neck pain is common in high performance jet pilots, with incidents frequently attributed to high G_z flight maneuvers. The additional load of helmet-mounted night vision goggles (NVG) is believed to increase the risk, possibly from neck muscle strain in counteracting muscles. Hence, the aim was to investigate the effect of NVG on neck muscle strain as well as on the activity level distribution through a simulated flight session in air force pilots.

METHODS: In this post hoc randomized crossover trial, four senior air force pilots each completed two identical 1.5-h dynamic flight simulations in a human centrifuge: one with a standard helmet and NVG, and one with a standard helmet only. Simulations included repeated exposure to 3–7 G_z, during which neck muscle activity was recorded bilaterally from the anterior neck, the upper and lower posterior neck, and the upper shoulders. The number of muscle activities surpassing 50% of maximum voluntary electrical activity (MVE) and total time of activity at each MVE percentile were compared between NVG and control flights.

RESULTS: There was no overall effect in number of neck strain activities between NVG and control flights; however, significantly more activities emerged in the anterior neck. In addition, MVE percentile data showed a tendency of higher activity in the lower posterior neck during NVG flights.

CONCLUSIONS: The results showed that the additional load of helmet-mounted NVG increases neck muscle strain in anterior stabilizing muscles, indicating that the inertia of head-worn NVG elevates the risk of flight-related neck pain.

KEYWORDS: EMG, muscle activity, neck pain, night vision goggles.

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According to recent data, 83% of fighter pilots have experienced neck pain during or immediately after flight within the preceding year.[13] Increased exposure to higher and more rapid change in acceleration, combined with the implementation of helmet-mounted night vision goggles (NVG), is believed to increase in-flight neck muscle activity. This provides a partial explanation for pilots' neck pain, considering the strong relationship between internal loads and muscle activation level[16] and the positive correlation between acceleration and neck muscle activity.[2] According to Newton's second law of motion, increased G results in a person being exposed to a force corresponding to the acceleration multiplied by that person's mass. Thus, during 5 G an individual of 80 kg is subjected to forces equivalent to 400 kg. The mean acceleration magnitude for the occurrence of neck pain has been reported to be 6.7 G;[23] however, with unexpected acceleration and aircraft movements that possibly lead to postural perturbations of the head and neck, this magnitude can be substantially lower.[6] In agreement with this, peak neck muscle strain of up to 80% of maximum voluntary electrical activity (MVE) has been reported among fighter pilots during typical air combat maneuvers (ACM),[7] which significantly exceeds the previously defined level for muscle strain of 50% MVE.[11,18, 19]

NVG are used to enhance pilots' vision during flights in dark conditions. The additional weight of the NVG shifts the head's center of gravity forward, which increases the load on the

From the Department of Neurobiology, Care Sciences and Society, Karolinska Institutet, Huddinge, Sweden; the Department of Aeronautical and Vehicle Engineering, KTH Royal Institute of Technology, Stockholm, Sweden; Estavia, Uppsala, Sweden; SAAB Aeronautics, Saab Ltd, Linköping, Sweden; the Center for Clinical Research Dalarna, Falun, Sweden; and the Karolinska University Hospital, Stockholm, Sweden.

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Address correspondence to: Björn O. Äng, Karolinska Institutet, Department of Neurobiology, Care Sciences and Society, Division of Physiotherapy, Alfred Nobels allé 23 100, SE-141 83 Huddinge, Sweden; Bjorn.Ang@ki.se.

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posterior muscles.[15] To prevent this, a counterweight is commonly attached on the rear part of the helmet, which reduces the flexion moment of the neck; however, head position seems to have greater influence on the induced neck load than the increased head-worn mass.[22] Previous studies have investigated mean in-flight muscle activity,[2] but few focused on peak muscle strain that may occur during postural perturbations or high G. To date, only one study has investigated the effect of NVG on air force pilots' neck muscle activity in controlled conditions, and it focused on the mean muscle activity during defined G plateaus.[2] Results from that study showed a somewhat greater neck muscle activity during sustained combat maneuvers, but not during any other G circumstances, including high-G episodes.[2]

In this post hoc study, we used the continuously collected data from that study, with the aim of examining effects on peak strain and muscle activity magnitudes during controlled simulated flights representing the whole flight mission. Such data on high neck muscle activity (peak strain) has been requested in international scientific forums.

METHODS

In this randomized crossover repeated-measure study, data from a previous study[2] was reanalyzed with the focus on peak neck muscle strain and overall neck muscle activity over the entire flight mission (methodological details on data collection has been presented elsewhere,[2] but key information is presented below). Each pilot completed two simulated flight programs in a randomized order: one with helmet and NVG, and one with helmet only. Between trials, a washout period of a minimum 7 d (mean 16 d) was deemed sufficient. The study protocol was approved by the local Medical Research Ethical Review Board and, before data collection began, all subjects gave their written consent to participate.

Subjects

Initially six senior fast-jet test pilots were recruited from either the Flight Test and Verification Group at the Swedish Air Force, or from the Defense Material Administration and Saab Aerosystems Ltd. All pilots flew the JAS 39 Gripen and had experience with NVG equipment, including the counterweight, from jet flights at up to 6–7 G or more. Inclusion criteria were pilots on active duty with former experience of using NVG and counterweight equipment during JAS 39 Gripen high-G flights. Exclusion criteria were ongoing neck pain or pain induced by the testing procedure. This resulted in the withdrawal of one subject during the first test program. The remaining five subjects had a mean (SD) age of 40 yr (4.2), weight of 85 kg (4.2), and height of 1.84 m (0.04). Their total flight time was 2570 h (758), and flight time in the past 12 mo was 85 h (28.0). Three subjects reported previous neck and back pain episodes, with one occurring during the 3 mo prior to testing.

Equipment

A dynamic flight simulator (Wyle Laboratories Inc., El Segundo, CA) with an interior design based on the JAS 39 Gripen aircraft (SAAB Ltd., Linköping, Sweden) was used to simulate high-G flight conditions. The gondola contained real aircraft hardware such as a Martin-Baker ejection seat (Martin-Baker Aircraft Co. Ltd., Middlesex, UK), stick and throttle (Page Aerospace Ltd., Middlesex, UK), and oxygen regulator (Honeywell Aerospace, Yeovil, UK). Seat-back angle was equivalent to the 28° seatback in the JAS 39 Gripen and the simulation was presented in front of the pilots in their line of sight on three 20" LCD monitors (mounted u-shaped; total width: 1.2 m, approximately 0.9 m distance from the eyes). To get a realistic flight experience, a unique conception algorithm which modeled the expected sensations created a real flight impression.

All pilots wore complete flight suit equipment, including full coverage anti-G protection (G valve scheduled), helmet (116H; SAAB Ltd.), and a counterpressure bladder integrated into the flight jacket for assisted positive pressure breathing during high-G maneuvers. The NVGs were composed of an NVG dummy and a counterweight, biomechanically identical to genuine equipment (total weight including helmet around 3 kg). A helmet-integrated NVG dummy of the same weight and center of gravity as genuine NVG equipment was used for safety reasons, as having light inside the gondola to facilitate visual inspection of the pilots by camera monitoring and in case of emergency was necessary.

Muscle activity was measured using an established EMG protocol previously used in pilots[1,3,22] and skydivers,[14] and applied according to current recommendations.[9] Electrode placement areas were shaved, sandpapered, and disinfected with 70% alcohol. Next, disposable, bipolar, self-adhesive electrodes with pre-gelled surface discs and an active diameter of 10 mm (Ag/AgCl, Blue Sensor N-00-S, Medicotest A/S, Ølstykke, Denmark) were attached pairwise, with an interelectrode distance of 20 mm. EMG signals were preamplified 1000 times, band-pass-filtered at 20–500 Hz and run through a 12-bit A/D converter with a sampling frequency of 1 kHz (Mega Muscle Tester, Mega Electronics Ltd, Kuopio, Finland).

EMG activity was recorded from four muscles bilaterally (**Fig. 1**): the anterior neck (the lower part of the sternocleidomastoid muscle belly), the upper posterior neck (splenius capitis muscle), the lower posterior neck (the erector spine muscle between C7 and T1, 20 mm lateral to the spinous process), and the upper shoulders (trapezius descendens at the anterolateral margin, midway between the occiput and acromion). To eliminate the risk of EMG wires interfering with the pilots during the flight program, the wires were placed inside the pilots' flight suits.

Procedure

MVE was obtained by subjects pushing their heads against manual resistance in extension (upper/lower posterior neck), flexion (anterior neck), and shoulder elevation (upper shoulders). Subjects were instructed to push with increasing force up to maximal voluntary force and hold for 3 s in order to avoid injury and minimize the risk of dynamic contractions. The maximal reference contractions were conducted in a functional neutral position,[10] with subjects sitting in the gondola's flight seat. Three trials were done, with 1 min rest in between in order

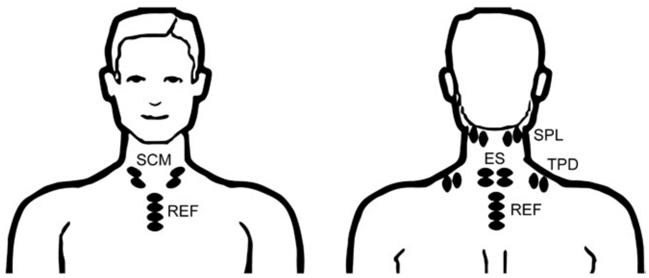

Fig. 1. EMG electrode placement used for all subjects. SCM – sternocleidomastoid muscle, SPL – splenius capitus muscle, ES – erector spinae muscle, TPD – upper trapezius muscle, and REF – reference electrodes.

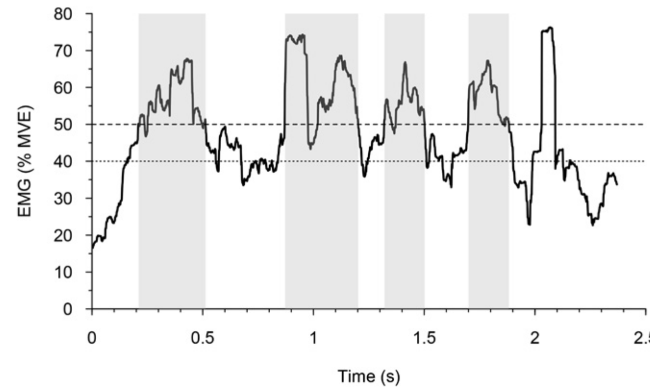

Fig. 2. Example of muscle strain activities (gray areas), defined as activity episodes surpassing 50% MVE (dashed line) for more than 100 ms. Note that activity was required to decrease below 40% MVE (dotted line) in order to be counted as a new strain activity.

to enhance MVE stability, and the mean of the two highest trials was defined as MVE.

Flight simulation protocols of 150 min total, developed and validated by a panel of medical and engineering experts, as well as experienced pilots, were used.[2] All protocols started with a 60-min simulation at Earth's gravity to familiarize the subjects with the task (the gondola was static), followed by dynamic 90-min flight simulations (the gondola was dynamic). The dynamic flight was initiated with 5 min of "free warm-up flight" in a closed-loop manner and included 17 unique G exposure episodes at 3–7 G_z, counting ACM. The 3 G_z and 7 G_z exposures were sustained for 15 s and the ACM were sustained for 100–120 s. The pilots' total G exposure was 420 s at 3 G_z, 315 s at 5 G_z, and 45 s at 7 G_z. Between G exposure episodes there was a rest of at least 2 min at 1.4 G_z to permit physiological recovery, and profiles were initiated with successively increasing onset rates to a maximum of 6 $G_z \cdot s^{-1}$. To avoid possible systematic biases, subjects were randomly allocated to start with NVG or control simulations. The pilots were instructed to follow the flight simulation on the screens and avoid large head and neck movements under high G conditions.

Statistical Analysis

EMG data was rectified and smoothed with a 100-ms root mean squared moving average (Matlab v8.0, The Mathworks, Natick, MA) and normalized as the percentage of reference activity (MVE). The total number of muscle strain activities surpassing 50% MVE for more than 100 ms were counted using an automated script, which required activity to drop below 40% MVE in order to qualify as a new peak (example illustrated in **Fig. 2**). Further, duration of muscle activity for each MVE percentile was extracted.

Technical problems resulted in data loss for one subject's right lower posterior neck, which was replaced using the last observation carried forward technique (i.e., the value for the left upper neck was used for the right upper neck). Further, another subject had missing data in all channels in the later phase of the NVG flight program, and was excluded from the subsequent analysis. In total, data from four subjects were analyzed, three starting with the standard setup (helmet only) and one with helmet and NVG.

The paired-sample test for count data[20] was used to analyze within-subject differences (helmet + NVG vs. helmet only) in number of muscle strain activities, with $P < 0.05$ defined as statistically significant. Duration of muscle activity for each MVE percentile was assessed visually.

RESULTS

Table I displays the number of identified peak muscle strain activities during the simulated flight for 1.5 h. In total, there were 157 and 118 muscle strain activities, respectively, during the NVG and control programs ($\chi^2_1 = 0.44$, $P = 0.505$). Significantly more peaks were observed in the anterior neck during the NVG simulation (18 vs. 1; $\chi^2_1 = 8.09$, $P = 0.004$) and no other differences were found.

Fig. 3 shows the duration of muscle activity for each MVE percentile for the respective data sampling locations. Results showed a slight offset toward higher activity in the lower posterior neck during the NVG program compared to the control; the curve representing NVG shifted to the right. No other between-group differences in overall muscle activity were observed.

DISCUSSION

The main finding of this study was that NVG caused significantly more muscle strain activities in the anterior neck. Further, a trend of higher muscle activity over the complete flight simulation was observed in the lower posterior neck. These results were consistent with our hypothesis that NVG increases muscle strain.

Whereas 33% more (157 vs. 118) muscle strain activities were observed for all muscles during NVG than control simulations, this difference was not statistically significant, possibly due to having a small sample and a large variance. This is in line with the results of our original study.[2] Conversely, significantly more muscle strain activities (18 vs. 1) were identified for the anterior neck, which is consistent with previous findings.[21] While the neck flexors are known cervical spine

Table I. Number of Muscle Strain Activities Over 50% MVE, as Obtained During Flights with Helmet-Mounted Night Vision Goggles (NVG), and Helmet Only (CTRL).

	ANTERIOR NECK		UPPER POSTERIOR NECK		LOWER POSTERIOR NECK		UPPER SHOULDERS	
SUBJECT	NVG	CTRL	NVG	CTRL	NVG	CTRL	NVG	CTRL
1	11	0	1	0	5	0	83	69
2	1	0	0	7	3	2	8	16
3	0	0	0	0	27	1	5	1
4	6	1	0	0	4	9	3	12
Sum	18	1	1	7	39	12	99	98
P (χ^2_1)	0.004 (8.09)		0.267 (1.23)		0.123 (2.37)		0.600 (0.28)	

P-value based on a Chi-squared (χ^2) distribution with one degree of freedom.

stabilizers,[4] their force generating capacity is substantially lower than that of the posterior neck,[12] rendering it possible that the additional activity required to maintain cervical stability with additional helmet weight during +1 G_z exceeded a critical threshold.

Peak muscle strain episodes are potentially harmful for internal structures, but while it is plausible to assume that the risk for pain or injuries increases with their frequency, no rationale for minimum duration relevant to pain exists. Hence, to minimize the risk of strain activities relevant for pain incidence being excluded, we defined muscle strain as activity exceeding 50% MVE for more than 100 ms, whereas previous studies required it to be sustained for more than 1 s.[18,19] This shorter cutoff duration increased the likelihood of false strain activities due to alternating activity around 50% MVE. To avoid this, activity had to drop below 40% MVE to qualify as a new strain activity (illustrated in Fig. 2). Despite our shorter cutoff duration, the total amount of muscle strain episodes observed was relatively low compared to an earlier study.[18] A possible explanation for this is that our subjects were instructed to avoid large head movements during trials in order to minimize the risk of injury. In previous studies without this restriction, the head has been reported away from a neutral position in 67% of ACM duration,[7] and pain-inductive muscle strain as high as 257% has been observed.[18] Thus, our results are likely underestimated, considering that the elevated helmet weight with mounted NVG equipment increases muscle strain in positions deviating from a neutral posture.

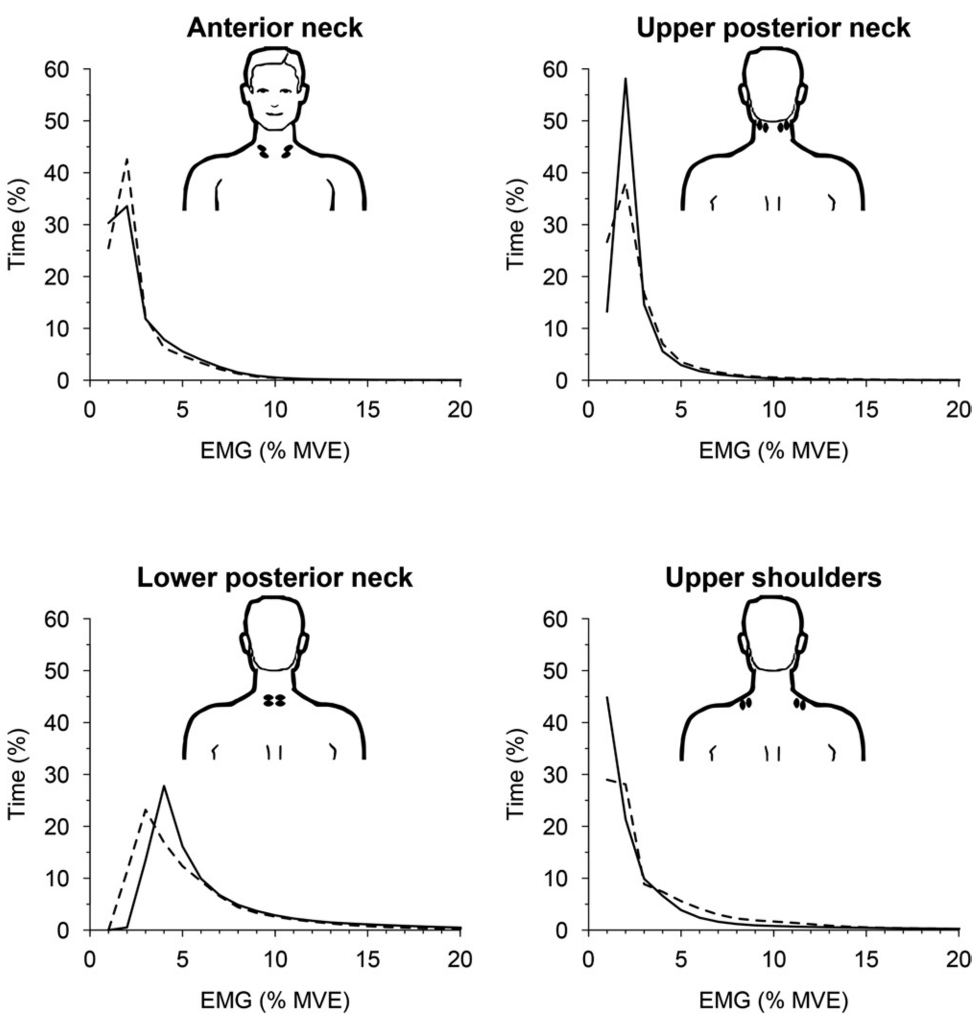

Fig. 3. Temporal distribution of normalized EMG activity for each MVE percentile. Solid and dashed lines mark NVG and control flights, respectively.

Although the overall activity magnitude over entire simulations was low relative to MVE, a trend toward a slightly higher activity was observed in the lower posterior neck during the NVG program. This difference is relevant, as small changes in EMG activity could indicate relatively large changes in induced load during static neck postures.[5] Further, to avoid unacceptable strain in static work exceeding 1 h in duration, it has been recommended that muscle activity should not exceed 2% MVE and must not exceed 5% MVE.[11] A possible explanation for this trend not being statistically significant is that the strain on the posterior neck muscles decreases close to the end of the motion range, as the cervical spine becomes dependent on its passive structures in a forward head spine posture.[8]

In contrast to earlier studies which focused on muscle activity during G plateaus or selected parts of the flight,[2,7,18] this study analyzed muscle activity over the complete flight duration, which facilitates extrapolation of our results to a real in-flight environment. However, while our pilots had similar demographics to those of previous air force pilot studies,[7,17] the small sample leaves this study open to both type II error and selection bias. Moreover, the randomization used to determine whether pilots initiated measurements with NVG or not is intended for balanced groups, but the exclusion of two pilots resulted in three pilots starting measurements without NVG while only one started with NVG. This imbalance may have influenced results, although it was at least 7 d between test occasions.

Our results suggest that the additional load of helmet-mounted NVG increases neck muscle strain in anterior stabilizing muscles, indicating that NVG elevates the risk of flight-related neck pain. A tendency of slightly higher overall activity in the lower posterior neck further supports this conclusion, although the small sample size leaves our findings sensitive to biases. Moreover, additional research is needed to evaluate whether increased neck muscle activity actually depends on increased helmet weight, head movements, or an interaction between them.

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Authors and affiliations: Magnus Wallquist Pousette, PT, M.Sc., Riccardo Lo Martire, PT, M.Sc., and Björn O. Äng, PT, Ph.D., Department of Neurobiology, Care Sciences and Society, Division of Physiotherapy, Karolinska Institutet, Huddinge, Sweden; Jan Linder, M.D., Ph.D., Estavia Lakarkonsult Ltd., Läkarhuset, Sweden; and Mats Kristoffersson, M.Sc., Saab Aeronautics, SAAB Ltd., Linköping, Sweden.

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