Posture and Helmet Load Influences on Neck Muscle Activation

Michael F. Harrison; Kelsey A. Forde; Wayne J. Albert; James C. Croll; J. Patrick Neary

INTRODUCTION: Night vision goggles (NVG) are linked to increased neck muscle activation and pain. Counterweights (NVGcw) are hypothesized to mitigate these effects. The purpose of this study was to investigate the muscular response to varying helmet loads and postures.

METHODS: Volunteering from a representative squadron were 16 male helicopter aviators (pilots, $N = 9$; flight engineers, $N = 7$). Subjects performed head movements to assume nine different postures (three directions: left, center, and right, at three different levels: down, level, and up) with four different head loads (no helmet; helmet only; NVG; and NVGcw) in randomized order. Subjects were provided real time visual guidance and feedback while assuming the appropriate posture in a cockpit seat in a laboratory setting. Neck muscle activation was assessed with electromyography (EMG) of four different muscle groups, bilaterally, including the sternocleidomastoid, splenius capitis, and mid and lower trapezius.

RESULTS: Two- to fourfold increases in muscle activation were observed in postures to the left (down, level, and up) while subjects wore either the NVG or NVGcw as compared to the baseline of no helmet. This was most prevalent in smaller muscle groups (i.e., the sternocleidomastoid and splenius capitis) as compared to larger muscle groups (i.e., the mid and lower trapezius).

DISCUSSION: The use of NVGcw did not decrease neck muscle activity as compared to NVG only, particularly when the head posture moved the field of view below the horizon. This suggests interventions to decrease neck muscle activity and fatigue in military helicopter aircrew using NVG should focus on task specific guidelines with respect to countermeasures.

KEYWORDS: night vision goggles, helicopter, rotary wing, neck strain, counterweight.

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The helicopter flight helmet has been described as "a mounting platform for numerous combat-essential devices."[3] As a result, the presence of night vision goggles (NVG) and other head-mounted equipment for helicopter aircrew has become standard operational equipment during low light operations. In the Canadian Forces, the 2.1-kg helmet becomes a 3.7-kg mass when equipped with NVG (1.0 kg) plus counterweight (0.6 kg) (NVGcw).[24] This additional head-borne mass has been linked to injury to the cervical region of the spine that is often insidious in nature as a result of increased mass, extreme postures, and multiple or prolonged exposures.[1,22,25] Rates of neck pain vary greatly in the literature, with British results ranging from 30 to 80%,[25] while Swedish and American results suggest that 50–60% of aircrew experience neck pain.[2,23] In the Canadian military, 90% of helicopter pilots with >150 h of NVG flight experience report flight-related neck pain.[1] A flight helmet will have a mass of between 1.3 kg and 2.2 kg, depending on the model, while a flight helmet with NVGcw will have a mass of 3.7 kg.[7,8,24] Thuresson et al.[21] demonstrated increased muscle activity, as assessed with electromyography (EMG), during different postures with NVG and with NVGcw as compared to the helmet alone. Our previous work demonstrated increased metabolic activity as a result of NVG and counterweight use, independent of cockpit seat location, on the metabolic and neuromuscular aspects of the superficial

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cervical muscles.[12–14] The increased metabolic activity as a result of the additional head-supported mass was also found to be a result of duration of exposure. Forde et al.[6] reported significant increase in cumulative physical work performed during simulated NVG missions as compared to simulated daytime missions for pilots as a result of the additional mass and the decreased field of view (i.e., loss of peripheral vision).[4]

With these findings in mind, the present study investigated the effects of different helmet configurations (i.e., helmet only vs. helmet with NVG vs. helmet with NVGcw) on the neuromuscular activity of the superficial cervical muscles during discrete head movements specifically designed to simulate a pilot's in-flight movement pattern(s), i.e., the location of specific flight instruments and postures. Based on our previous findings, we hypothesized increased muscle activity, as assessed with EMG, would be observed during tasks involving head movements to bring the field of view below the horizon while the pilot's helmet was loaded with NVG and NVGcw.[12–14] Again, based on these findings and the work of others, we expected to observe an increase in neuromuscular activity in the small muscle groups, particularly on the right side of the spinal column.[5,10,14]

METHODS

Subjects

Ethical approval was obtained from the University of Regina Ethics Review Board. There were 16 male aircrew (9 pilots, 7 flight engineers, ages 35.3 ± 4.9 yr, height 1.78 ± 0.08 m, weight 82.1 ± 12.4 kg, helicopter flight experience 680.38 ± 629.92 h) from a CH-146 tactical helicopter squadron who volunteered to participate in the study and provided informed consent.

Equipment

Subjects were tested under four head loading conditions that were randomly ordered: no helmet (HEAD), +0 kg; helmet only (HELMET), +1.6 kg; NVG, +2.4 kg; and NVGcw, +3.1 kg. Subjects presented with their standard-issue individual flight helmet to ensure optimal fit. The locations of the center of gravity in each configuration, determined mechanically by triangulation, are illustrated in **Fig. 1**. The NVG and NVGcw equipment used in the testing laboratory was identical in all testing sessions with all subjects.

Procedure

Subjects were seated in a standard cockpit seat with 4-point safety harness engaged. The seat was mounted on standard seat rails on a mount placed on the floor in a laboratory setting; the seat was oriented to face a wall on which six pieces of standard letter size (21.6 cm × 27.9 cm) colored paper were placed as visual targets to guide each movement and posture. Two additional pieces of paper were mounted on top of plastic boxes to the left and right of the seat, approximately 30 cm off the ground; a final piece of paper was placed on a box that was approximately 60 cm off the ground and placed directly in front of the cockpit seat. The nine postures were determined to represent nine representative postures during normal flight (**Fig. 2**). These included Up & Left, Up & Center, Up & Right, Level & Left, Level & Center (LC, neutral position), Level & Right, Down & Left, Down & Center, and Down & Right. Fig. 2 provides a visual summary of what these postures correspond to in the cockpit. Subjects moved from the LC or neutral posture to each assigned posture in a random sequence under each different head-loading condition, maintained that posture for 5 s to simulate the frequent changes in posture associated with tactical flight,[15] and then returned to LC. Subjects were instructed to perform each movement with the same speed and technique as they would use under normal flight conditions. The order of each head-loading condition was also randomly determined for each subject. A laser pointer was mounted on the helmet during the HELMET, NVG, and NVGcw trials and on a sport visor during the HEAD trials. The position of the laser dot was adjusted to the center of the subject's gaze when their eyes were focused directly forward. This provided real-time feedback to the subject and the researchers during the individual trials to ensure all subjects had assumed a posture that would achieve the same field of view during comparable trials. Subjects performed three trials of each head movement under each head-load condition to ensure data values were successfully obtained (i.e., no lost data due to electrode nonadherence to skin in a dynamic setting) for each subject in each scenario. The values were averaged for each subject for each movement and head-load setting.

Fig. 1. The centers of gravity in each testing configuration: A) HEAD; B) HELMET; C) NVG; D) NVGcw.

Eight 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, right and left sternocleidomastoid, right and left upper trapezius, and right and left lower trapezius muscles (**Fig. 3**). Electrode placement was determined using predetermined measurements based on anatomical landmarks (SENIAM, Enschede, the Netherlands). Placement sites were shaved as needed for hair removal, cleaned

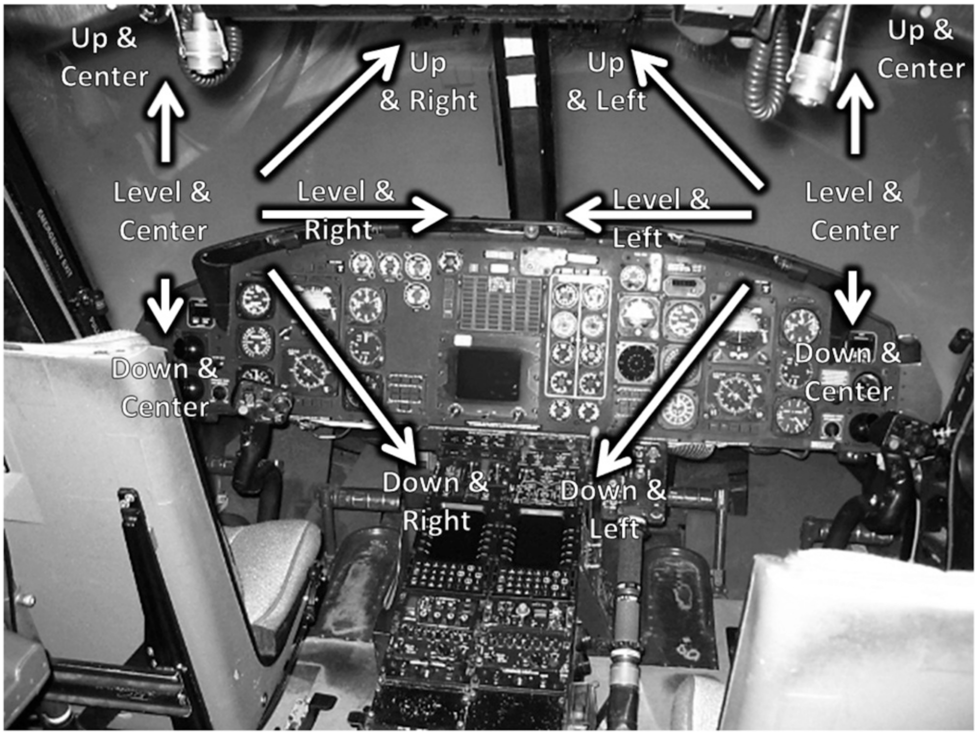

Fig. 2. Illustration of nine representative postures.

with 70% alcohol swab, and lightly abraded with fine sandpaper. A reference electrode was affixed over the bony protuberance of C7[17] and signal quality was visually assessed with custom oscilloscope software (U.S. Army Aeromedical Research Laboratory, Ft Rucker, AL) through the subject's performance of a series of test movements such as neck flexion/extension and shoulder shrugs. Electrodes were either reinforced with adhesive tape or replaced as needed between trials if there was concern they had become dislodged.

Statistical Analysis

Custom MATLAB software (The MathWorks, Natick, MA) calculated the root mean square (RMS) value for each of the submaximal workloads under three different conditions: assuming the posture (TO), maintaining the posture for 5 s (HOLD), and returning to neutral posture (BACK). RMS was calculated during the 0.5-s interval associated with the greatest EMG signal for each of the TO, HOLD, and BACK conditions. These values were standardized to the values for the neutral posture (LC) under the HEAD condition and reported as relative values to this measurement. A general linear model repeated measures analysis of variance (ANOVA) with Greenhouse-Geiser test was performed and Bonferroni post hoc analysis identified significant differences within subjects between the different head-borne conditions. Significance was set at $P \leq 0.05$.

RESULTS

The mean EMG RMS results ± SDs with *P*-values and degrees of freedom as compared to HEAD trials are summarized in **Table I**. A full summary of normalized RMS values and statistical results for each muscle group, movement, and helmet condition can be found in the online supplemental material [**Appendix A** and **Appendix B** (10.3357/AMHP.4301sd.2015)].

The NVG configuration resulted in significantly increased muscle activation in nine settings (combinations of posture, movement phase, and helmet load) when compared to HEAD while the NVGcw configuration resulted in significantly increased muscle activation in 10 settings. The significant findings are summarized in Table I with the normalized RMS values as compared to the HEAD setting presented. Furthermore, the NVGcw configuration resulted in trends toward significance in seven settings. The HELMET configuration was comparable to HEAD in the muscle activity profile recorded with only two significant results. Significant increases in muscle activity were more likely to occur during tasks that required the aircrew member to adjust their gaze below the horizon. This was also more likely to occur in postures that required deviation toward the left. Significant increases in EMG signal were more likely to be observed in the smaller muscles (i.e., the splenius capitis and sternocleidomastoid) as compared to the larger muscles (i.e., right and left upper trapezius, right and left lower trapezius).

DISCUSSION

This study provides a quantitative analysis of increased muscular activity as assessed by EMG signal under different head loading conditions using dynamic movements and postures that are ergonomically associated with in-flight postures. NVGcw and NVG loading conditions were associated with increased muscle activation as compared to the HEAD and HELMET trials. The differences were particularly evident in postures below the horizon and to the left in the smaller muscle groups (the splenius capitis and sternocleidomastoid). Additionally, a number of findings were trending toward significance with $P < 0.10$. While the magnitude of the difference was small in the present study, it is likely these differences would be amplified over the course of a 2-h mission with NVG or NVGcw; the addition of other in-flight stresses such as vibration would be very likely to further augment the magnitude of the neuromuscular response.

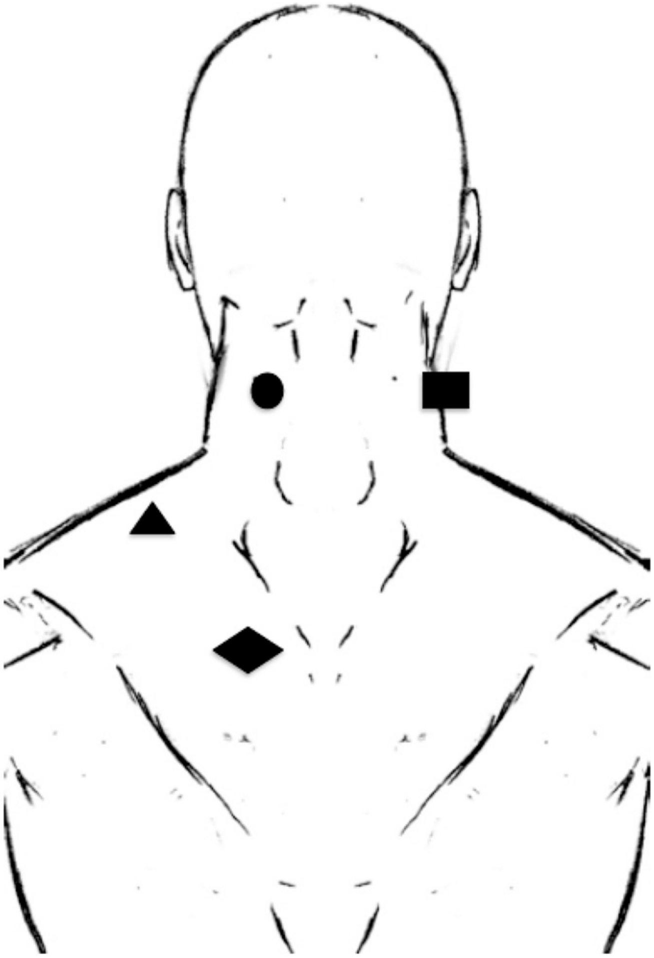

Fig. 3. Illustration of EMG electrode placement. Black circle: splenius capitis; black square: sternocleidomastoid; black triangle: upper trapezius; black diamond: lower trapezius.

Table I. Summary of Significant Differences Between HEAD and NVG or NVGcw Configurations.

NVG	NVGcw
UL	
	SCML (HOLD): 2.52 ± 0.39 (< 0.01)
	SCML (BACK): 3.37 ± 0.56 (0.02)
LL	
SpCL (TO): 4.40 ± 0.60 (0.02)	upTL (HOLD): 1.56 ± 0.27 (0.04)
SpCL (HOLD): 2.35 ± 0.41 (0.03)	
DL	
SpCL (HOLD): 3.08 ± 0.31 (0.01)	SpCL (HOLD): 3.10 ± 0.42 (0.01)
SpCR (HOLD): 2.39 ± 0.25 (0.01)	SpCR (HOLD): 2.48 ± 0.32 (0.01)
	lowTR (HOLD): 1.40 ± 0.08 (0.04)
UC	
SpCR (HOLD): 1.76 ± 0.27 (0.02)	SCML (HOLD): 2.74 ± 0.41 (0.03)
SCML (BACK): 3.60 ± 0.58 (0.02)	
lowTR (HOLD): 1.82 ± 0.26 (0.04)	
DC	
	lowTR (BACK): 1.43 ± 0.14 (0.05)
UR	
SCML (HOLD): 2.25 ± 0.38 (0.02)	lowTR (HOLD): 1.37 ± 0.13 (0.02)
DR	
SpCR (BACK): 4.27 ± 0.46 (0.05)	SpCR (BACK): 4.15 ± 0.54 (0.05)
	SCMR (BACK): 1.97 ± 0.21 (0.01)

NVG: night vision goggles; NVGcw: night vision goggles with counterweights; UL: up & left; LL: level & left; DL: down & left; UC: up & center; DC: down & center; UR: up and right; DR: down & right; SCML: left sternocleidomastoid; SCMR: right sternocleidomastoid; SpCL: left splenius capitis; SpCR: right splenius capitis; upTL: left upper trapezius; lowTR: right lower trapezius; TO: moving the head To the required position; HOLD: Hold phase of the head movements; BACK: returning to neutral position.

The use of NVG has often been associated with increased incidence of flight-related neck pain reported in the Canadian,[1] British,[25] Swedish,[2] and Dutch[22] militaries. Piloting a helicopter under tactical flight conditions is a dynamic task that requires frequent movement of the head and neck.[15] Our efforts to date have illustrated the increased metabolic demand[14] and the increased head/neck mobility with subsequent cumulative loading[6] during simulated NVG/NVGcw missions as compared to Day missions. Forde et al.[6] also noted increased movements to bring line-of-sight below the horizon during the NVG/NVGcw missions that are hypothesized to result in the decreased field of view associated with NVG use.[4] Our present results further support the conclusions made by Forde et al.[6] with respect to increased load and stress on the structures of the neck during NVG/NVGcw missions and highlight the significance of the reported finding that NVG use is associated with increased movements to bring the line-of-sight below the horizon.

Our current results suggest both NVG (9 statistically significant differences compared to the HEAD trial) and NVGcw (10 statistically significant differences compared with the HEAD trial) increase the strain placed upon the cervical musculature as compared to the HEAD and HELMET conditions. The NVGcw condition was more likely to produce significant increases in neuromuscular activity; this is the opposite effect from the intended benefit that influenced its design and use. In the present study, these differences were most noticeable in postures that directed the line of sight below the horizon, correlating with the location of many important flight instruments. Under such conditions, the NVGcw would be contributing to a downward moment that would require increased muscle activity to support the head and the increased load. Furthermore, these differences were also observed in the dynamic phase of the task, i.e., moving TO or moving BACK, for postures that directed the line of sight above the horizon; in postures that directed the line of sight below the horizon, it was the static phase of the task, i.e., HOLD, that demonstrated the most significant differences. Our earlier research suggested NVGcw mitigated the metabolic stress of the trapezius muscles during simulated NVG/NVGcw missions.[14] However, this finding was obtained in an analysis of near infrared spectroscopy data, collected every 2 s, from the trapezius muscles over the full duration of a simulated mission (approximately 2 h). As this study's results suggest, it was the smaller muscles that were most affected and it was during specific movements and postures. Thuresson et al.[20] provided a static biomechanical analysis that suggested a benefit in a neutral posture, but the benefit was lost when the subject assumed a flexed posture. In our recent literature review, one of our recommendations was "perhaps not every crewmember has an in-flight posture and loading profile that warrants the use of NVGcw."[9] This data lends support to that statement.

More differences were observed in the movements toward the left side. However, the musculature on the right side was more likely to be the source of the statistical difference. Our previous results also found the right-sided musculature to be the most prone to increased stress and metabolic activity during simulated missions regardless of cockpit seat side,[13,14] independent of seat side.[12] Other studies have noted an increased right-sided muscular stress as measured with EMG in the lumbar musculature.[5,16] This has been hypothesized to be attributable to the in-flight posture adopted by pilots to manipulate the cyclic and the collective.[18] A limitation of our study was the lack of cyclic and collective in the laboratory setting. Our subjects were seated without a predisposition to rotate partially to the left to operate the flight controls. As a result, the in-flight stress during postures toward the right may not be accurately reported in the present results due to the lack of cyclic and collective controls; our subjects may have been seated in a posture with less leftward "twist" toward the flight controls than has been previously described in this population[18] and, as a result, the musculature on the left side of the neck may have experienced different stress under the various loading conditions and postures.

However, our present results indicate the smaller muscles are more prone to increased muscular activity as a result of NVG and NVGcw, whereas NVGcw use was more likely to also increase the neuromuscular activity in the larger trapezius muscle groups. Our prior studies have demonstrated the smaller muscles to be more prone to fatigue during submaximal efforts in a comparable population.[10,11] This further supports the suggestion by Salmon et al.[19] to incorporate neck-specific training regimens in the list of operational duties. Wickes and Greeves[25] provided an early argument that general fitness and regular physical activity provided a protective benefit against flight-related neck pain.

No significant differences were observed for the HELMET only trial. While it may be hypothesized that differences may be observed during the HELMET setting in longer periods of activity approaching the 2-h average mission length or the extreme 5-h "longest" mission length our subjects have reported previously,[9] it should be noted that our methodology altered how our subjects would normally function in this setting. Under normal operational conditions during HELMET or daylight conditions, Forde et al.[6] demonstrated decreased cervical movement that is a result of the aircrew members' reliance on peripheral vision. For our purposes in the current study, the subjects were required to physically move to direct their gaze to a series of specific targets, possibly exaggerating any potential differences that might exist.

With respect to limitations, five obvious issues should be addressed. The lack of cyclic and collective in our laboratory setting may have minimized the observed effects during postures toward the right side. Further work, preferably in a cockpit rather than a laboratory simulation using a cockpit seat, would address this adequately. However, this can be difficult to coordinate in the schedule of busy operational and training squadrons who may not have an available airframe to dedicate for a substantial period of time to a research project. Secondly, a number of our results trended toward significance with $P < 0.10$. Our sample size and randomization were chosen to economize the time required from our research subjects, who were operational squadron members with other responsibilities. The sample size was selected based on review of other EMG results in helicopter aircrew,[5] but should be an impetus to include more subjects in future studies. Additionally, our trial occurred over a period of approximately 60 min of combined movement with all the different headload conditions, approximately 60 min shorter than the average NVG mission in the Canadian Forces.[14] Our results do not quantify the effects of fatigue, a variable that prior research has demonstrated to be a contributing factor to neck pain in this population,[10,11] based on shorter duration of testing session coupled with random order of headload conditions. Furthermore, our research protocol was specific to pilots and neglected the various duties and requirements of the position of flight engineer or load master. Further studies are needed to examine the effects of various helmet loads on these individuals as their job often requires extremely dynamic movements to extremes of their ranges of motion.[25] Lastly, these additional studies should investigate what, if any, performance decrements are associated with prolonged use of differing helmet-mounted head masses among the different aircrew populations.

In conclusion, the use of NVGcw does not provide relief to the muscular structures of the neck in the form of decreased neuromuscular activity as assessed by EMG when compared to NVG settings when an aircrew member is required to adopt a posture that deviates from neutral or level. This difference was most notable in the smaller musculature on the right side and particularly when the movement was toward a posture on the left side.

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