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Neck Muscle Activation and Head Postures in Common High Performance Aerial Combat Maneuvers

Kevin J. Netto and Angus F. Burnett


Introduction: Neck injuries are common in high performance combat pilots and have been attributed to high gravitational forces and the non-neutral head postures adopted during aerial combat maneuvers. There is still little known about the pathomechanics of these injuries.

Methods: Six Royal Australian Air Force Hawk pilots flew a sortie that included combinations of three +Gz levels (1, 3, and 5) and four head postures (Neutral, Turn, Extension, and Check-6). Surface electromyography from neck and shoulder muscles was recorded in flight. Three-dimensional measures of head postures adopted in flight were estimated postflight with respect to end-range of the cervical spine using an electromagnetic tracking device.

Results: Mean muscle activation increased significantly with both increasing +Gz and non-neutral head postures. Check-6 at +5 Gz (mean activation of all muscles = 51% MVIC) elicited significantly greater muscle activation in most muscles when compared with Neutral, Extension, and Turn head postures. High levels of muscle co-contraction were evident in high acceleration and non-neutral head postures. Head kinematics showed Check-6 was closest to end-range in any movement plane (86% ROM in rotation) and produced the greatest magnitude of rotation in other planes. Turn and Extension showed a large magnitude of rotation with reference to end-range in the primary plane of motion but displayed smaller rotations in other planes.

Discussion: High levels of neck muscle activation and co-contraction due to high +Gz and head postures close to end-range were evident in this study, suggesting the major influence of these factors on the pathomechanics of neck injuries in high performance combat pilots.

Keywords: electromyography, neck, cervical, hypergravity, injury.

Work-related musculoskeletal disorders have a high impact on modern, industrialized society and it has been estimated that these disorders cause between 25–33% of all sick-leave taken in the work place (25). Neck pain and its associated disability accounts for a sizable proportion of work-related musculoskeletal disorders, with a 1-yr prevalence of up to 76% in specific occupations (4). The etiology of neck pain is multifactorial and has been attributed to the physical, psychological, and social stresses of work (4,25). However, work-related musculoskeletal disorders of the neck have been largely attributed to an increased mechanical demand on the supporting structures and musculature of the neck (29).

Neck pain is a common complaint of high performance combat pilots (HPCP), often resulting in lost workdays and reduced functional performance (12,14,18). Cervical spine pathology, which may lead to pain and disability such as fractures of the cervical vertebrae, stenosis of the spinal canal, cervical disk prolapsed, and premature disk degeneration, have all been attributed to prolonged exposure to high acceleration and deceleration forces while flying. These forces are measured in multiples of the force due to gravity (G) and are commonly the result of aerial combat maneuvers (ACM) (12,18,22). In some cases HPCP may have their flying careers restricted or prematurely ended by neck injury (2,13,15).

Neck muscle activation as measured by surface electromyography (EMG) recorded in flight has shown that HPCP are exposed to high mechanical loads. Activation levels between 20% and 80% of maximum voluntary isometric contraction (MVIC) have been recorded from the sternocleidomastoid and cervical erector spinae musculature in flight (14) while peak levels of activation of 257% MVIC have also been reported for the sternocleidomastoid at high +Gz (23), although the method of normalization of this data may be questionable (21). These high levels of neck muscular activation have been considered to be causative of neck injury (12,14,23). Further, the weight of equipment such as flight helmets and helmet-mounted night vision goggles necessary for the HPCP have been known to exacerbate stress in the neck region (26). This strongly suggests that the head-neck system and its related structures and musculature are ill prepared to withstand the high loads associated with ACM.

High incidences of neck pain have been reported when HPCP perform high (> 5) +Gz maneuvers with the head in a non-neutral position (18). Incidences of...
NECK INJURY PATHOMECHANICS IN-FLIGHT—NETTO & BURNETT

neck injury at lower (< 4) +Gz, especially when +Gz onset is unexpected, has also been documented (12). Previous investigations have estimated three-dimensional head positions adopted in flight and showed several examples of non-neutral postures that are typically adopted during flight (3,12,16). The quantification of these postures, however, was not related to the pilot’s cervical range of movement, which would seem to be an important consideration based on previous research (9). Panjabi (24) hypothesized the existence of two separate zones of motion in the spine. The first zone, namely the neutral zone, encompasses movement from the neutral position to a posture where properties of high flexibility and laxity cease. Conversely, the elastic zone is defined as the area between the end of the neutral zone and end range and is characterized by high passive spinal stiffness. By knowing where in range the head and neck are being positioned with respect to end range, an assessment of head posture relative to these zones can be made, thus increasing our understanding of the pathomechanics of neck injury.

It has been hypothesized that there is a predominantly mechanical cause to neck injuries in HPCP (12,22,23); however, there is still little known regarding the pathomechanics of neck injury in this unique occupational group. Therefore, the purpose of this study was twofold. Firstly, to examine the activation of selected neck and shoulder muscles using EMG recorded in flight in four typical ACM-related head postures and three different +Gz levels. Secondly, due to the methodological difficulty in determining three-dimensional head posture during flying, the head postures examined in the study were approximated postflight by asking pilots to repeat the head postures adopted in flight. These postures were described relative to the pilot’s cervical range of motion (ROM), thus allowing an improved understanding into the mechanisms of neck injury.

METHODS

Subjects

Six Royal Australian Air Force (RAAF) pilots from No. 79 Squadron participated in the study. The subjects included five trainee fighter pilots (mean ± SD age: 23.2 ± 1.2 yr; height: 1.78 ± 0.04 m; weight: 82.5 ± 8.4 kg; flying time: 375 ± 23 h) and one fast jet instructor (45 yr, 1.76 m, 80 kg, 6400 flying hours, respectively). All pilots were medically fit and were deemed operational at the time of testing. During the flights, each subject wore standard RAAF flying equipment that included a flying-suit (0.8 kg), G suit (1.5 kg), lightweight helmet/visor (1.2 kg, Gentex HGU-55/P Gentex, Cardonale, PA), oxygen masks (0.5 kg, MEL Aviation MO3110/MO3109, MEL Aviation, Suffolk, UK), lifejacket (4.2 kg, Bernhardt Apparebau, Holm, Germany), leg restraints (0.4 kg, Martin Baker, Middlesex, UK), boots, and gloves.

Ethical and technical approval for the study was obtained from the Australian Defense Force Human Research Ethics Committee, RAAF 78 Wing Group, RAAF 79 Squadron, and the Human Research Ethics Committee, Edith Cowan University. Inclusion criteria as outlined by Sommerich et al. (30) for neck EMG measurement was adopted and informed consent obtained was from each subject prior to the commencement of testing.

Experimental Protocol

The Lead-In Fighter Hawk 127 (BAE Systems, BAE International, Edinburgh, SA, Australia) twin-seater single engine jet was used as the test aircraft. Synchronized neck and shoulder EMG data and video footage were collected during a specially designed sortie (designed by squadron fast-jet instructors) that incorporated three representative +Gz levels (specifically +1 Gz, +3 Gz, and +5 Gz) and four common head postures typically adopted during ACM. The pilots flew the aircraft and simultaneously performed the prescribed head postures as follows:

- Neutral—maintenance of a self-selected neutral head posture with an approximately upright thorax and while looking straight ahead;
- Extension—extension of the head through the top of the canopy;
- Turn—axial rotation of the head to look into a right turn of the aircraft; and
- Check-6—looking to the rear of the aircraft for adversaries.

Both Turn and Check-6 were only performed with right turns of the pilot’s head and aircraft and this was confirmed with the video footage taken during flight. To eliminate systematic bias, the ordering of the +Gz level to be tested was randomized. However, all head postures within a specified +Gz level were completed prior to the next +Gz level being tested. The four head postures were randomized within each +Gz level. An example of the sortie structure with the corresponding +Gz levels and head postures is outlined in Table I.

Subjects executed the sortie as instructed in the flight briefing and would initiate the desired +Gz level with an appropriate flight maneuver. Pilots then adopted the four head postures while continuing to keep +Gz at the desired level. Each head posture was held for approximately 3 s with the head being repositioned to neutral for 3 s before adopting the next head posture. To facilitate accurate synchronization of EMG recordings, subjects were instructed to verbalize each head posture as they adopted it so it could be detected on the audio channel of the video camera. Once all head postures for the corresponding +Gz level had been completed, the subject leveled the aircraft at +1 Gz and commenced a 2-min rest period to allow full physiological recovery. Each test at a specific +Gz level lasted approximately 60 s and the whole protocol was completed within 10 min. Video and audio footage allowed synchronization of EMG onset is unexpected, has also been documented (12). Previous investigations have estimated three-dimensional head positions adopted in flight and showed several examples of non-neutral postures that are typically adopted during flight (3,12,16). The quantification of these postures, however, was not related to the pilot’s cervical range of movement, which would seem to be an important consideration based on previous research (9). Panjabi (24) hypothesized the existence of two separate zones of motion in the spine. The first zone, namely the neutral zone, encompasses movement from the neutral position to a posture where properties of high flexibility and laxity cease. Conversely, the elastic zone is defined as the area between the end of the neutral zone and end range and is characterized by high passive spinal stiffness. By knowing where in range the head and neck are being positioned with respect to end range, an assessment of head posture relative to these zones can be made, thus increasing our understanding of the pathomechanics of neck injury.

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<table>
<thead>
<tr>
<th>+Gz</th>
<th>Head Posture</th>
</tr>
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<tbody>
<tr>
<td>3</td>
<td>Extension</td>
</tr>
<tr>
<td>1</td>
<td>Check-6</td>
</tr>
<tr>
<td>5</td>
<td>Turn</td>
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</table>

TABLE I. AN EXAMPLE OF A SORTIE USED IN THE STUDY.
of EMG recordings to the +Gz level and head postures and the video footage was later used as a basis for subjects to reproduce in-flight head postures postflight.

Electromyography: Surface EMG signals were collected from eight sites (four locations recorded bilaterally) around the neck and shoulder region. The muscles that were investigated along with the specific electrode placements are summarized below:

- Left and right sternocleidomastoid (LSCM, RSCM)—1/3 distance from the sternal notch to mastoid process, over the main belly muscle (21);
- Left and right levator scapulae (LLSC, RLSC)—Midway between the posterior border of sternocleidomastoid and the anterior border of the upper trapezius (21);
- Left and right cervical erector spinae (LCES, RCES)—10 mm from the spinous process at the C4/5 level in a bipolar configuration and placed between the anterior margin of the trapezius and the midline of the body, in line with muscle fibers (21); and
- Left and right upper trapezius (LUTR, RUTR)—Lateral to the midpoint between C7 and the posterior acromion shelf, along the line of upper trapezius muscle fibers.

Excess body hair was removed and the area was abraded, then cleaned with an alcohol swab. Pairs of 12-mm diameter Ag-AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN) were adhered to the skin with a 20-mm center-to-center distance along the muscle fiber orientation. An impedance meter was then used to ensure an impedance reading of < 10 kΩ prior to collection. Separate ground placements for each channel were placed on the bony prominence of the clavicle. EMG signals were sampled at 1000 Hz via an eight channel portable data logger (ME3000P8, Mega Electronics, Kuopio, Finland) with miniature analog differential amplifiers (bandwidth: 8–500 Hz; common mode rejection ratio: 110dB; gain: 375). Signals were digitally recorded by the data logger onto a 32-MB flash memory PCMCIA standard card.

Prior to takeoff, subjects performed a series of MVICs for the purpose of EMG data normalization. A portable cable dynamometer, which has been previously found to generate MVICs with high reliability (21), was used to elicit MVICs of selected muscles in head flexion, extension, and lateral flexion, and in shoulder elevation. Subjects performed three repetitions of a 5-s MVIC in a non-neutral posture.

On completion of the normalization trials, the data logger was secured in the leg pocket of the subject’s flight suit. All wires ran inside the subject’s flight suit to minimize the potential for interference during flight. Subjects finished final suit-up and were briefed on how to operate the data logger. The subject then proceeded to the flight line for takeoff. Once pilots had taken off and reached the predetermined flight zone, the data logger was triggered ‘on’ and checked for correct functioning. The data logger remained operational through the duration of the flight.

Head kinematics: Due to the logistical and technical difficulty in accurately determining three-dimensional head postures in flight, head postures were simulated postflight from the in-flight video footage using an electromagnetic tracking device (3-Space Fastrak, Polhemus Navigation Sciences Division, Colchester, VT). The device consists of an electromagnetic source (transmitter), a systems electronic unit, and two receivers (each of which has a three-dimensional coordinate system embedded) and is known to be accurate to 0.2°. The magnetic source was securely fixed to a wooden frame and this was placed 0.2 m in front of the sitting subject at seated shoulder height. The sensors were placed on the main protuberance of the forehead and the supra-sternal notch allowing rotations of the head relative to the thorax to be recorded (6).

After removal of the EMG electrodes and attachment of the receivers, the subjects were seated in a non-ferrous chair to ensure no magnetic interference. The seat back angle of the chair was approximately 80° and the seat back angle in the aircraft was similar (approximately 70–80°). Comments by HPCP prior to testing indicated that they did not use the seat back for support during ACM. Also, this slight discrepancy between the angulations of these seats was taken into account through our data analysis methods where head postures were calculated relative to the thorax. Firstly, active ROM of the neck was measured in flexion/extension, lateral bending, and axial rotation, and this was performed three times. The in-flight video was then shown to the subject along with their flight protocol. The subject was instructed to simulate each of the three non-neutral head postures (Extension, Turn, and Check-6). For each of these postures, subjects rotated their head from the neutral posture to the appropriate non-neutral posture and then back to neutral. Each of these postures was recorded three times and the order of testing was randomized.

Data Processing

EMG signals were downloaded from the data logger using MegaWin V2.0 (Mega Electronics, Kuopio, Finland) software running on a laptop PC. Files were then exported as ASCII text files to a customized LabVIEW V6.1 (National Instruments Inc., Austin, TX) program. Raw EMG data were then demeaned, high-pass filtered at 15 Hz to remove any movement artifact, full wave rectified, and low-pass filtered at 4 Hz to produce a linear envelope.

MVIC values were obtained from the average of the last two of the three maximal contractions (29) and a 200-ms moving window was applied to the linear envelope. In-flight EMG signals were sectioned by means of the time stamp on the in-flight video and voice recordings of the subject verbalizing each +Gz level and head posture combination. The beginning of each +Gz/ head posture combination was clearly seen as there were distinct bursts of EMG activity in the agonistic muscles that corresponded to the head postures in the experimental protocol. These data were then processed in exactly the same fashion as the MVIC signals.

Kinematic data obtained postflight from the Fastrak were analyzed in a customized LabVIEW V6.1 (Na-
differences in activation existed between the left and right side for each muscle. Further, intra-class correlation co-efficient (ICC) calculated as a two-way mixed model and relative standard error of measurement (%SEM) values were calculated to determine within-subject repeatability of head kinematic data when each head posture was repeated postflight (21). All statistical tests were conducted using SPSS version 14 (Chicago, IL).

RESULTS

The level of muscle activation when considered as an average of all eight muscles examined in this study was significantly lower (p = 0.001) at +1 Gz (16% of MVIC) when compared with +3 Gz (24%) and +5 Gz (33%) (Fig. 1). Further, average muscle activation was significantly greater (p ≤ 0.02) for all head postures when compared with the Neutral posture (Fig. 1). The Check-6 head posture elicited significantly greater muscle activation when compared with both the Turn (p = 0.001) and Extension (p = 0.009) head postures. There was no significant difference evident (p = 0.216) for the level of muscle activation between the Turn and Extension head postures.

LSCM at +5 Gz displayed the highest level of activation of all muscles examined (71.5% MVIC) and this occurred when the Check-6 posture was adopted (Fig. 2). There were significant differences (p ≤ 0.026) evident between head postures for the level of muscle activation for all individual muscles at +5 Gz with the exception of LUTR (p = 0.351). Post hoc comparisons

**Statistics**

The overall effect of +Gz and head posture on the normalized level of muscle activation was analyzed using a repeated-measures one-way ANOVA with the dependent variables being the average muscle activation from the eight muscles investigated in this study. All variables were assumed to be independent in this study. Prior to performing the ANOVA, the Shapiro-Wilks test for normality was performed on the dataset with data being judged as normally distributed (p > 0.05). Where a significant effect from the ANOVA was with data being judged as normally distributed (p < 0.05), post hoc comparisons were made using Tukey’s “honest significant difference” test for pair-wise comparisons. Activation of each muscle between head postures was also examined at the +5 Gz level using a repeated-measures one-way ANOVA. At this +Gz level, independent sample t-tests were also performed between each head posture to determine

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**Fig. 1.** Normalized muscle activation across all muscles with varying +Gz level grouped by aerial combat maneuver-related head postures. X indicates the mean value and dots indicate individual subject data. *Significant difference when compared with +1 Gz (p = 0.001). †Significant difference when compared with +3 Gz (p = 0.001). ‡ Significant difference when compared with Neutral (p ≤ 0.02). § Significant difference when compared with Extension (p = 0.009). ¶ Significant difference when compared with Turn (p = 0.001).

**Fig. 2.** Individual neck muscle activation at +5 Gz. X indicates the mean value and dots indicate individual subject data. *Significant difference when Neutral was compared with Check-6 (p ≤ 0.023). † Significant difference when Neutral was compared with Turn (p ≤ 0.048). ‡ Significant difference when Neutral was compared with Extension (p ≤ 0.006). § Significant difference when Extension was compared with Check-6 (p ≤ 0.046). ¶ Significant difference when Turn was compared with Check-6 (p ≤ 0.041).
demonstrated that the Check-6 head posture elicited significantly higher levels of activation when compared with Neutral (p ≤ 0.029) in all muscles except RLSC and LUTR, and Extension (p ≤ 0.021) except in RSCM, RLSC, LSCM, and LUTR. Check-6 did not elicit significantly higher activations when compared with Turn (p ≥ 0.085) except in RSCM. In a majority of cases muscle activation levels were also not significantly different when Neutral was compared with Extension (p ≥ 0.115) except in RSCM, LSCM, and RUTR. However, significant differences were noted when Neutral was compared with Turn (p ≤ 0.041) except in RCES, RUTR, LCES, and LUTR. No significant differences in muscle activation were found for any muscle when Turn was compared with Extension (p ≥ 0.027) except in RSCM. LUTR was the only muscle not to exhibit any significant change in muscle activation (p = 0.115) in all four ACM-related head postures. Also, it was revealed that LSCM and RSCM were the only muscle pair to exhibit a significant difference between the left and right sides (p ≤ 0.029) and these differences only occurred in the Check-6 and Turn head postures. There was, however, a trend toward differences between LUTR and RUTR in the Extension (p < 0.09) and Turn (p < 0.10) head postures.

High levels of within-subject reliability were observed when postflight estimation of in-flight head kinematic data were analyzed (ICC values > 0.83, %SEM ≤ 7%). This confirmed the minimization of repositioning errors between repeated trials. Therefore, estimations of in-flight head postures were repeatable and a mean value of the three repeat trials was subsequently used for statistical comparisons (Table II).

All rotations of the head with respect to the thorax were measured from the Neutral position (which was deemed to be 0°, 0°, 0°). Therefore, only the Turn, Extension, and Check-6 head postures were examined. Neck ROM data obtained in this study (extension = 63.4 ± 4°, axial rotation = 70.6 ± 5°, lateral bending = 52.1 ± 9°) were consistent with previous age- and sex-matched data (27), therefore providing evidence for validity of the ROM data from this study. The non-neutral head postures produced large amounts of rotation in the primary plane of movement (68–87% ROM) with the Check-6 head posture being closest to end range in any movement plane (87% ROM in axial rotation). Both the Turn (68% ROM in axial rotation) and Extension head postures (73% ROM in extension) showed a large magnitude of rotation with reference to end range in the primary plane of motion. The Check-6 head posture produced the greatest magnitude of rotation in other planes (31% ROM in lateral bending, 34% ROM in extension) when compared with the Turn and Extension head postures (32% ROM in lateral bending, 20% ROM in extension, and 14% ROM in lateral bending; 14% ROM in axial rotation, respectively) (Fig. 3).

### DISCUSSION

Reports of neck injury in HPCP are commonplace in the aviation medicine literature and it has been suggested these injuries are caused by repetitive exposure to combinations of hypergravity and non-neutral head postures experienced during ACM (18,22). However, more in-depth knowledge of the pathomechanics of neck injury in this unique occupational group is less well known. This study quantified the level of activation in key neck and shoulder muscles, in addition to estimating the three-dimensional position of the head with respect to end-range of motion of the cervical spine, when HPCP performed typical ACM. It was hypothesized that increasing +Gz levels and adopting head postures closer to end range would significantly increase muscle activation levels.

Significant increases in neck and shoulder muscle activity with increasing +Gz was observed in this study, which is in agreement with previous studies examining neck muscle activity and hypergravity in HPCP (12,14,23). The level of muscle activation recorded from the neck flexors and extensors in this study was similar to previous investigations when similar head postures and +Gz levels were scrutinized (12). To our knowledge no previous studies have reported in-flight measures of neck lateral flexor and shoulder elevator muscle activation; therefore, these values could not be compared with other studies. Interestingly, levels of muscle activation at +5 Gz recorded in this study were similar to those recorded in studies simulating low-velocity rear impact collisions (19).

At +5 Gz, LUTR was the only muscle that did not show a significant difference for the level of muscle activation between ACM-related head postures. Although not statistically different, there was a trend to-

**TABLE II. WITHIN-SUBJECT REPEATABILITY OF HEAD KINEMATIC DATA WHEN EACH HEAD POSTURE WAS REPEATED POSTFLIGHT.**

<table>
<thead>
<tr>
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<th>Axial Rotation</th>
<th>Extension</th>
<th>Lateral Bending</th>
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<tbody>
<tr>
<td></td>
<td>ICC %SEM</td>
<td>ICC %SEM</td>
<td>ICC %SEM</td>
</tr>
<tr>
<td>ROM</td>
<td>0.89 3.8</td>
<td>0.91 2.1</td>
<td>0.91 2.6</td>
</tr>
<tr>
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<td>Extension</td>
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<td>0.90 2.6</td>
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</tr>
<tr>
<td>Turn</td>
<td>0.95 2.4</td>
<td>0.94 2.2</td>
<td></td>
</tr>
<tr>
<td>Check-6</td>
<td>0.83 6.5</td>
<td>0.85 2.4</td>
<td>0.85 6.9</td>
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Fig. 3. Head position relative to range of motion (%ROM) in the three non-neutral ACM-related head postures. X indicates the mean value and dots indicate individual subject data.

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ward varying levels of muscle activation between LUTR and RUTR for the Extension and Turn head postures. This can be attributed to the setup of the cockpit controls, where pilots typically have the left arm in an abducted position so that the left hand is able to control the throttle. Having the arm abducted by more than 30° has been shown to increase shoulder loads significantly in static occupational tasks (10) and this may minimize shoulder musculature contributions toward head and neck stabilizations. Further, greater activation levels were noted in the LSCM when compared with the RSCM during Check-6 and Turn. The difference in the level of muscle activation in these ACM can be attributed to the pilots turning their head to the right when the aircraft also turns to the right. This requires the LSCM to be the agonistic muscle, thus its level of activation is increased.

Due to constraints with aircraft hardware and avionics, hardware synchronization of +Gz data to EMG signals was impossible. However, evidence of pre-activation of the neck and shoulder muscles prior to sudden aircraft acceleration was noted in most subjects when video and EMG data were analyzed with time synchronization. Consequently, HPCP would probably be anticipating sudden +Gz onset with ACM; therefore, the mechanism of neck injury similar to that of whip-lash-associated disorders should be discounted (28). The need for stabilization of the head in ACM is a requirement for safe aircraft operation and this is a vital function of the neck and shoulder musculature when flying a high performance aircraft. In this study, high levels of muscle co-contraction were evident. For example, RLSC and LLSC, RCES and LCES, as well as RUTR and LUTR, were highly active, especially at +5 Gz and the Check-6 head posture (Fig. 2). Musculoskeletal modeling studies that have examined cervical spine mechanics have shown that high levels of neck muscle co-contraction exacerbate compressive loads in the cervical spine (8). High compressive and shear forces may in turn cause damage to the active and passive structures of the cervical spine (12). Since combinations of high +Gz and non-neutral head postures are common in ACM (12), high levels of muscle co-contraction may be a cause of the neck injuries sustained by HPCP.

Estimates of in-flight head kinematics obtained post-flight by pilots repeating typical head postures clearly showed that the three typical non-neutral ACM-related head postures examined in this study exhibited large amounts of motion in the primary plane of movement. This places the cervical spine into near end-range postures and, therefore, into the elastic zone (24), where stress and strain on passive structures of the cervical spine would be increased and may lead to injury. Two further mechanisms of neck injury in HPCP related to end-range postures may be possible. Firstly, the moment-generating capacities of the neck musculature in non-neutral postures have been found to be decreased in studies measuring isometric neck strength in non-pilots (11,30). Also, non-significant differences in neck strength have been shown when HPCP were compared with non-pilots and exposure to +Gz has not led to significant increases in isometric neck strength (26). Therefore, the combined findings of these studies suggest that the neck and shoulder musculature has a diminished capacity to produce force in such postures and hence the structures of the cervical spine are left vulnerable to injury, especially when high loads due to increased +Gz are experienced. Secondly, the passive structures of the cervical spine are thought to develop high reactive forces to spinal movement in these postures (24), suggesting that if the musculature of the neck is unable to withstand the high loads of hypergravity, these structures may be injured.

In this study, the Turn and Check-6 head postures exhibited components of axial rotation combined with extension. It has been previously found that the range of axial rotation in the cervical spine is significantly decreased when increasing amounts of extension are present. Specifically, increased extension has been shown to reduce the available ROM in axial rotation by as much as 37° bilaterally (6). This could imply that when HPCP adopt an extended head posture, their cervical spine may be actually closer to, or even at end range, possibly increasing stress and strain on the passive structures.

Examination of the kinematic and EMG findings from the present study suggest axial rotations in the cervical spine are present in a number of the ACM-related head postures. When +Gz loads are applied to the head’s mass, the head compresses into the thorax. This situation has been shown to be injurious, as in vitro analysis of the porcine cervical spine, which has been shown to exhibit similar biomechanical characteristics as the human cervical spine, showed decreased compressive strength when axial rotational torque was combined with compressive torque (5).

Many head postures and exposure to hypergravity as examined in this study are unavoidable when HPCP perform ACM. However, pilots should prepare their necks for this well-known occupational injury. Neck strengthening exercises and maintenance of flexibility has been postulated as a possible intervention strategy to prevent or delay neck injuries in HPCP (1,12,18). Such specific conditioning exercises have been shown to be beneficial to neck pain sufferers in various working populations (20). Significant gains in isometric neck strength (specifically in flexion and extension) have been reported after pilots performed a 6-mo supervised neck-strengthening program (1). The three-dimensional head posture data presented in the current study suggests that uni-planar flexion and extension strength exercises may lack specificity to counteract the high loads and multi-planar head movement seen in ACM. Thus, in future prospective studies of the efficacy of neck-strengthening exercises decreasing neck injury during ACM, the idea of incorporating both uni-planar and multi-planar neck and shoulder strengthening exercises should be investigated more thoroughly.

A perceived limitation of the current study may be the small sample size tested. However, highly significant results were found. Also, estimation of in-flight head kinematics was obtained post-flight as three-dimensional recording of head posture was deemed logistically difficult and potentially inaccurate.
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Conclusions

It is clear that neck injury in HPCP is a unique occupational hazard. Head stabilization is an important function of the neck and shoulder musculature in ACM. In this study, high levels of neck muscle activation and co-contraction due to high +Gz and head postures close to end-range of the cervical spine were evident. To further understand the pathomechanics of neck injury and incorporate targeted strategies for prevention, musculoskeletal modeling studies and studies examining efficacious strengthening of the neck and shoulder muscules is suggested.

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