RESEARCH ARTICLE

Neck Exercises Compared to Muscle Activation During Aerial Combat Maneuvers

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Introduction: Performing specific neck strengthening exercises has been proposed to decrease the incidence of neck injury and pain in high performance combat pilots. However, there is little known about these exercises in comparison to the demands on the neck musculature in flight. ***Methods:*** Eight male non-pilots performed specific neck exercises using two different modalities (elastic band and resistance machine) at six different intensities in flexion, extension, and lateral bending. Six Royal Australian Air Force Hawk pilots flew a sortie that included combinations of three $+G_z$ levels and four head positions. Surface electromyography (EMG) from selected neck and shoulder muscles was recorded in both activities. ***Results:*** Muscle activation levels recorded during the three elastic band exercises were similar to in-flight EMG collected at $+1\ G_z$ (15% MVIC). EMG levels elicited during the 50% resistance machine exercises were between the $+3\ G_z$ (9–40% MVIC) and $+5\ G_z$ (16–53% MVIC) ranges of muscle activations in most muscles. EMG recorded during 70% and 90% resistance machine exercises were generally higher than in-flight EMG at $+5\ G_z$. ***Discussion:*** Elastic band exercises could possibly be useful to pilots who fly low $+G_z$ missions while 50% resistance machine mimicked neck loads experienced by combat pilots flying high $+G_z$ ACM. The 70% and 90% resistance machine intensities are known to optimize maximal strength but should be administered with care because of the unknown spinal loads and diminished muscle force generating capacity after exercise.

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

MANY AUTHORS in the aviation medicine literature have suggested that neck strengthening exercises may be necessary for fighter pilots (3,7,11,19,20) to prevent neck injury. Recent research has indicated that performing specific neck conditioning exercises can significantly increase neck muscle strength (5), and strength and endurance (1) when compared with general exercises such as whole body or aerobic exercises (8). Furthermore, a program of specific neck conditioning exercises has been shown to increase neck strength and decrease neck pain in both women and men (24,30). Despite this evidence, the efficacy of specific neck exercise in the prevention and treatment of mechanical neck pain remains controversial (14,16).

High performance combat pilots are routinely exposed to high mechanical loads in non-neutral head positions and in moderate $+G_z$ levels (11,12,19). This may be the predominate cause of the high occurrence of neck injury and pain in this population. Neck strength increases are limited during the initial exposure to the moderate $+G_z$ environment in trainee pilots (4). Therefore, there may be a need to perform specific neck muscle strengthening exercises in the period where the trainee pilot's neck is relatively weak and has not adapted to the $+G_z$-related loading. In addition, there may be a need for more experienced pilots, who are routinely exposed to moderate $+G_z$ environments, to undertake specific neck exercises to decrease their predisposition to injury.

To increase muscle strength, acute training variables such as muscle action, loading (or intensity) and volume, exercise selection order, rest period, repetition velocity and frequency can be manipulated (2). The concept of periodization involves manipulating these variables to optimize the principal of overload by cyclically altering important variables such as loading and volume, thus placing ever-increasing demand on the neuromuscular system (23,29). Common exercise modalities used to increase neck muscle strength in a specific manner may include isotonic pin-loaded machines and elastic resistance devices. Devices such as pin-loaded, variable resistance exercise machines (Cybex International, Medway, MA) can readily alter exercise intensity through adjusting a pin-loaded stack. However, these machines are expensive, bulky and generally restricted to gymnasiums and rehabilitation centers. Conversely, elastic band latex tubing (Hygenic Corporation, Akron, OH) is inexpensive and highly portable. Elastic band tubing is available in color-coded bands of varying thickness, providing changes in resistance and theoretically increasing muscle loading. The exact difference in resistance provided by the tubing is dependent on factors such as starting length, the level of strain, rate of loading, and the particular joint the elastic band is being used to strengthen (26,27).

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Quantification of muscle loading during muscle strengthening exercises can be achieved by recording electromyography (EMG) from the muscle groups being exercised. EMG signals have been previously shown to increase significantly with an increase in exercise intensity in the arm, chest, and shoulder musculature (15,21). However, to our knowledge there are few studies that have characterized the neuromuscular load placed on the neck muscles during various specific strengthening exercises.

Neck strengthening programs have previously been designed for combat pilots and have resulted in increases in isometric neck strength (1,28). These training programs have incorporated modalities similar to the elastic band and pin-loaded resistance machine exercises, in addition to incorporating stretching, slow dynamic head movements, and the use of hand-held weights as resistance (1,13,28). Further, exercises that have attempted to simulate a $+G_z$ environment, such as trampolining, have also been shown to be beneficial to combat pilots by reducing neck muscle activations measured in flight (28). Previous studies, however, have concentrated on exercises that involve low to moderate loading of the neck, and no attempt has yet been made to compare these loads to those experienced by pilots during high $+G_z$ and non-neutral head positions. The aim of this study was to compare the levels of neck muscle activation in neck muscle training modalities (resistance machine and elastic band tubing) to those measured in flight during aerial combat maneuvers (ACM). The latter data have been previously reported in an earlier study conducted by our group (19). Such knowledge is necessary so that optimal training programs can be designed to ensure continuous overload in neck muscles for combat pilots with the view to preventing and rehabilitating neck injuries and pain in this population.

METHODS

Subjects

First, to provide the neck muscle activation data during specific neck exercises, eight male asymptomatic non-pilots [mean (SD), age 23.4 ± 5.1 yr, height 1.72 ± 0.10 m, and mass 71.3 ± 14.7 kg] were tested. Second, to provide the neck muscle activation data during ACM, six male Royal Australian Air Force pilots from No.79 Squadron participated in the study. The pilot cohort consisted of 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) who were medically fit and deemed operational at the time of testing. Specific details of the in-flight testing methodology will not be chronicled in this article; these can be found elsewhere (19). 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. (27) for neck EMG measurement was adopted and informed consent obtained was from each subject prior to the commencement of testing.

Experimental Protocol

As explained above, two different experimental protocols (and cohorts) were used in this study. The non-pilot cohort performed the specific neck exercise testing while the pilots performed the in-flight testing.

Specific neck exercise testing was undertaken on two different days with subjects attending a familiarization and neck strength testing session on the first day. Submaximal contractions in neck flexion, extension, and right lateral bending were also performed using both the Cybex (Cybex International, Medway, MA, herewith resistance machine) and Thera-Band (Hygenic Corporation, Akron, OH, herewith elastic band) training modalities. To provide relative exercise intensities for the resistance machine modality during EMG testing, subjects undertook a three-repetition maximum (3RM) test (17), in each of three directions (flexion, extension, and lateral bending). The second day of testing was conducted within 1 wk of the first session. Prior to testing, a warm-up consisting of 2 sets of 12 repetitions of unloaded contractions in each of the 3 directions was performed and subjects then stretched their neck musculature. A maximum voluntary isometric contraction (MVIC) in each of the testing directions was then performed for the purposes of EMG data normalization (27).

Three different exercise intensities were performed within the resistance machine and elastic band modalities. For the resistance machine, the exercise intensities were 50%,70%, and 90% of 3RM (herewith 50%, 70% and 90%) while the exercise intensities for the elastic band modality were the Green, Blue and Black elastic band tubing (herewith Green E-B, Blue E-B, and Black E-B). During EMG-testing, subjects were seated in a customized high-backed chair fitted with adjustable waist and shoulder straps to secure the torso firmly and to ensure the neck was isolated for both modalities. A customized testing platform consisting of a metal frame and rigid post was constructed to allow the attachment of the elastic band for the exercises and the cable for the MVICs.

For each training modality and exercise intensity, subjects performed two contractions in flexion, extension, and right lateral bending with the speed of contraction set at a count of "1-2" for the concentric phase and "3-4" for the eccentric phase. To identify the concentric and eccentric phases of each exercise in latter analysis, a motion analysis system was used to track a single retro-reflective marker placed on the apex of the subject's head. Contraction direction and intensity was randomized within each modality. To avoid excessive fatigue, 2 min of rest was given between each trial.

Elastic band tubing of 70 cm resting length was attached to an adjustable head harness via shackles, which in turn was attached to the post of the testing platform. To attach the elastic band to the subject, a head harness was worn. Subjects wore a latex swimming cap to minimize any slippage between this harness and the subject's head. The length that the elastic band was stretched during testing was an important consideration to control, as increased length of the elastic band would result in an increased resistance to overcome. The initial length of the elastic band was controlled in each trial, however, range of motion varied slightly between subjects. The approximate strain that the elastic band was under at the end point of the concentric phase of each exercise was 50%.

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 (SCM) — 1/3 distance from the sternal notch to mastoid process, over the main muscle belly (18);
- Left and Right Levator Scapulae (LS) — Midway between the posterior border of sternocleidomastoid and the anterior border of upper trapezius (18);
- Left and Right Cervical Erector Spinae (CES) — 10 mm from the spinous process at the C4/5 level in a bipolar configuration and placed between the anterior margin of trapezius and the midline of the body, in line with muscle fibers (18);
- Left and Right Upper Trapezius (UTR) — 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 and 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 obtained from the exercise testing were sampled at 1000 Hz and were amplified using a Grass amplifier system (Grass Instrument Co., Warwick, RI) (bandpass frequency, 10–450 Hz; input impedance, < 5 kΩ). The single 25-mm diameter retroreflective marker placed on the apex of the head was tracked for 5 s by a five-camera opto-electronic Motion Analysis System (Motion Analysis Company, Santa Rosa, CA) operating at 120 Hz. Data were automatically digitized and the 3-D points reconstructed. Vertical displacement of the marker was used to divide each exercise into its concentric and eccentric phases.

A series of MVICs for the purpose of EMG data normalization was performed prior to exercises. A portable cable dynamometer, which has been previously found to generate MVICs with high reliability (18), 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 neutral head position.

Data Processing

All EMG signals were downloaded from the various collection devices and exported as ASCII text files to a customized LabVIEW V7.1 (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 (27) and a 200-ms moving window was applied to the linear envelope. Flight EMG signals were sectioned by use of the time stamp on the in-flight video and voice recordings of the subject verbalizing each $+G_z$ level and head position combination. The beginning of each $+G_z$/head position combination was clearly seen as there were distinct bursts of EMG activity in the agonistic muscles that corresponded to the head position in the experimental protocol. These data were then processed in exactly the same fashion as the MVIC signals.

EMG signals recorded during the specific neck exercises were portioned into concentric and eccentric phases according to the synchronized kinematic data. To generate kinematic data (from the marker positioned on the head) at the same time base as the EMG data (i.e., 1000 Hz), a cubic spline was used. The subdivided EMG data were then time normalized (0–100%) using cubic spline interpolation. Only data collected from the agonistic muscles for each contraction was used for analysis. For example, in the extension direction, neck muscle activation collected from the posterior electrode placements was used and in flexion, the anterolateral electrodes were used, and in lateral bending only the posterolateral electrodes were used.

Statistics

As there were a large number of possible statistical comparisons to conduct in this study, descriptive statistics were chosen to compare neck muscle activation data obtained during the ACM to the data obtained from the specific neck muscle strengthening exercises. To generate a range of in-flight EMG values minimum and maximum neck muscle activations for each muscle were calculated for the three $+G_z$ levels. Minimum values were generated by averaging the EMG data from the left and right muscle pairs from the minimum activation during the Neutral head position and the maximum values were obtained during the Check-6 head position, which was defined as when the pilot was looking to the rear of the aircraft; however, the left and right sides for each muscle were not averaged due to its non-symmetrical nature. Similarly, peak levels of neck muscle activation in each of the specific neck muscle strengthening exercises during the concentric phase were also calculated for each of the muscle groups in each individual. These data were obtained from the concentric phase (as opposed to the eccentric phase) as higher muscle activation levels were noted in this phase of the exercises. Intra class correlation co-efficient (ICC) calculated as a two-way mixed model and relative standard error of measurement (%SEM) values were calcu-

TABLE I. WITHIN-TRIAL RELIABILITY OF MUSCLE ACTIVATION LEVELS RECORDED IN THE ELASTIC BAND AND RESISTANCE MACHINE EXERCISE MODALITY.

	Extension		Flexion		Lateral Bending	
	ICC	%SEM	ICC	%SEM	ICC	%SEM
Elastic Band						
Green	0.74	15.5	0.58	52.8	0.57	26.3
Blue	0.90	7.4	0.92	4.6	0.35	39.4
Black	0.87	12.1	0.36	61.3	0.27	44.5
Resistance Machine						
50%	0.86	12.2	0.90	16.4	0.76	21.9
70%	0.83	9.3	0.71	23.9	0.86	15.6
90%	0.86	6.4	0.87	12.1	0.68	16.4

lated to determine the within-trial reliability of the neck muscle activation data when each of the neck exercise modalities were used (18). Reliability data were calculated using SPSS version 14 (SSPS, Chicago, IL) while descriptive data calculations and graphing was performed using Statistica V6.1 (StatSoft Inc., Tulsa, OK).

RESULTS

Acceptable levels of within-trial reliability were observed for the level of neck muscle activation for the resistance machine modality at the three different intensities (ICC values 0.68–0.90, %SEM 9%–23%). However, large differences in reliability were recorded for the peak level of neck muscle activation during the concentric phase of the elastic band exercises (ICC values 0.34–0.90, %SEM 7%–61%). It is noteworthy that neck muscle activations data elicited while performing lateral bending exercises had lower reliability when compared with activations elicited during flexion and extension exercises. **Table I** outlines these data.

Fig. 1 demonstrates that increases in the level of neck muscle activation during selected ACM were evident with increasing +G_z with the exception of the neck extensors where the maximum was marginally higher at +3 G_z (54% MVIC) compared with +5 G_z (48% MVIC) ACM. The neck flexors displayed the greatest range of neck muscle activation during flight (9%–83% MVIC at + 5 G_z) while the neck lateral flexors displayed the least variation (3%–52% MVIC). Neck muscle activations were similar during the three elastic band intensities, however, the differences between the 50%, 70%, and 90% intensities for the resistance machine modality were relatively large (Fig. 1). The highest level of activation during the specific neck muscle strengthening exercises was recorded in CES (93% MVIC) during the 90% exercise. Muscle activation levels in UTR were low in all exercise modalities when compared with other muscles.

It is notable that the differences in the levels of neck muscle activation between the three intensities of the elastic band modality are overlapped by the within-trial reliability of the EMG measurements. Therefore, in our small sample size (n = 8), EMG is not capable of detecting the small differences in neck muscle activation elicited by the different elastic band tubing. However, EMG is clearly discriminative between the elastic band modality and the resistance machine modality, as well as between the intensities of the resistance machine modality.

Levels of neck muscle activation data recorded during the elastic band exercises were all greater than the minimum +1 G_z values for all muscles. Further, EMG levels elicited during 50% resistance machine intensity/modality were between the +3 G_z and +5 G_z range in all muscles. The 70% and 90% intensities for the resistance machine modality resulted in higher neck muscle activation levels for most muscles when compared with the upper limit of the +5 G_z muscle activation range. Neck muscle activation data for UTR did not follow this trend as EMG recorded at 70% was below the lower limit of +5 G_z and 90% was at the lower limit of +5 G_z. Only activation levels in SCM at +5 G_z exceeded the activations elicited during 70% and 90% exercise.

DISCUSSION

Neck injuries and pain in combat pilots are commonplace; these injuries have been suggested to be caused by the repetitive exposure to combinations of hypergravity and non-neutral head positions experienced during ACM (7,11,19). Specific neck strengthening exercises have been proposed by many researchers as a possible method of preventing and rehabilitating these injuries (7,11,19,20). However, there has been no enquiry pertaining to the specificity, type, or intensity of these exercises when compared with the demands on the neck musculature during ACM itself. Therefore, this study compared levels of muscle activation from four selected neck and shoulder muscles recorded during ACM to neck muscle activations elicited in specific elastic band resisted, and pin-loaded resistance machine, neck conditioning exercises.

The levels of muscle activation recorded during ACM from SCM and CES in this study were similar to the level of activation reported by previous research (11). The amount of time that each muscle was activated was not measured in this study, rather we have presented a range of neck muscle activations for comparison purposes. Previous research has established an inverse relationship between activation levels of SCM and CES and the total time spent at low levels of neck muscle activation (< 20% MVIC) and this represents the majority of the total time of ACM (11). Neck muscle activations above 60% MVIC during ACM have been reported, but these may result in less than 20% of the total time of flight (11). With these findings we could speculate that combat pilots need to increase the strength in their neck musculature to withstand the neck loads encountered during ACM. Further, once this increased strength is achieved, some form of maintenance of this strength must occur to ensure combat readiness.

Peak neck muscle activity in SCM, LS, and CES in most +1 G_z head positions as well as Neutral at +3 G_z and +5 G_z were similar to the peak activity elicited during the elastic band exercises. Further, the average level of muscle activation during the specific strengthening exercises was also at the lower end of that experienced during the +3 G_z ACM's. From this finding we could speculate that specific neck muscle exercises using elastic band may be useful for pilots who fly low

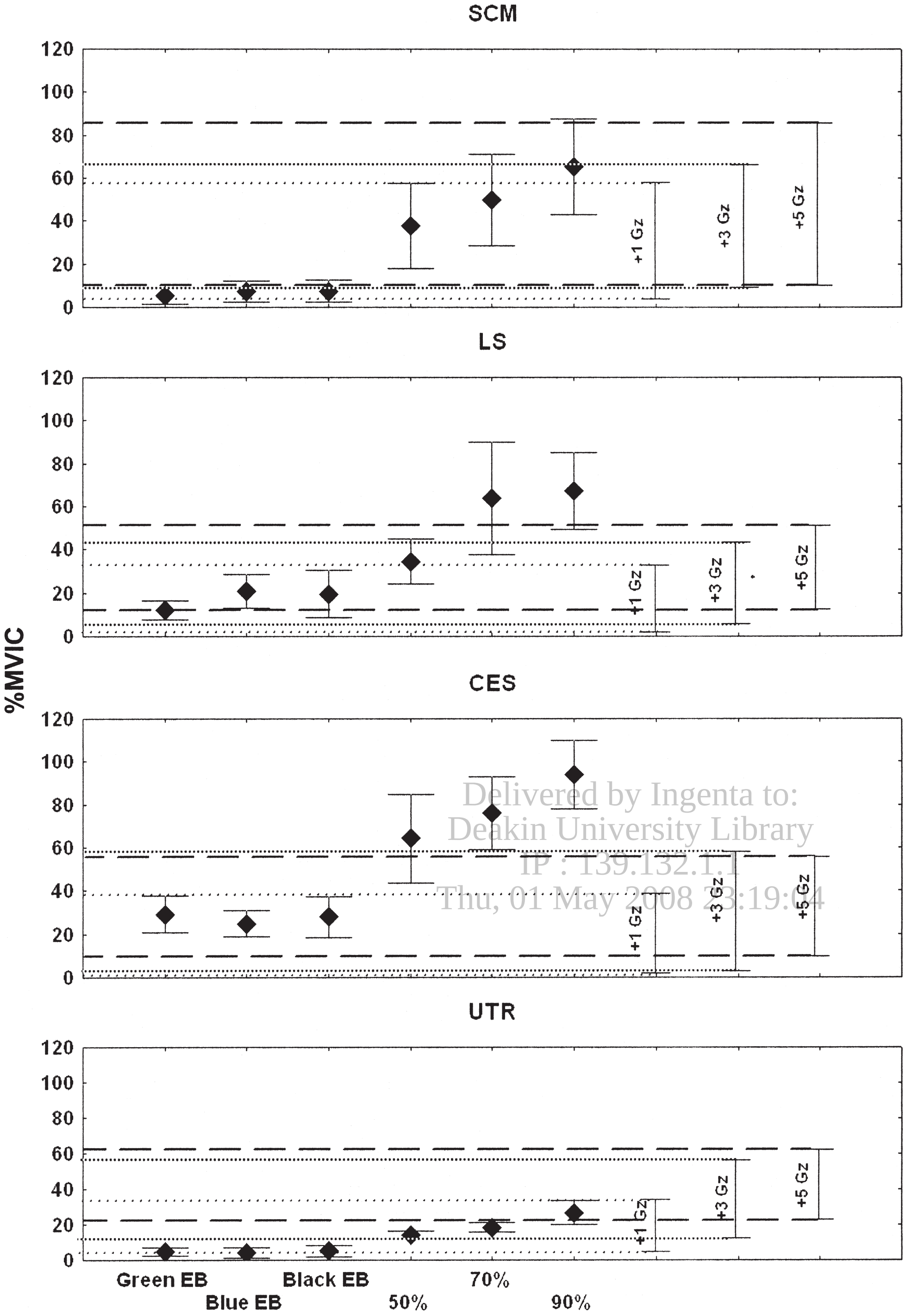

Fig. 1. Each graph depicts peak muscle activations for each neck conditioning exercise. The vertical axis gives levels of muscle activation as a percentage of MVIC. The lines on the graph show minimum and maximum muscle activation ranges at the three +Gz levels. Minimum activation was obtained during Neutral head position and maximum activation obtained during Check-6 head position. Dotted line represents minimum and maximum muscle activations during +1 Gz ACM; dashed line represents minimum and maximum muscle activations during +3 Gz ACM; and solid line represents minimum and maximum muscle activations during +5 Gz ACM.

+Gz missions or tend to keep their head in a more neutral position. This may apply to transport, bomber, and rotary wing pilots (7). The mean and peak muscle activity elicited in the 50% resistance machine intensity/modality was similar to the levels exhibited during the +5 Gz ACM, suggesting the usefulness of this exercise to mimic neck loads experienced by combat pilots flying high +Gz ACM.

In-flight neck muscle activations recorded for UTR during the specific neck muscle exercises did not result in values greater than the maximum value recorded for in-flight data collected at +1 Gz. This could be attributed to the use of shoulder restraints during the exercises, which limited shoulder elevation and the non-inclusion of specific UTR conditioning exercises in this study. UTR has been shown to be active during ACM especially when combat pilots adopt the Check-6 head position (19); therefore, specific strengthening exercises should be used to target this muscle. A number of specific UTR exercises may be prescribed by strength and conditioning professionals and physiotherapists and the most effective for UTR has been reported to be the unilateral shoulder shrug (10). Based on the results of the current study we believe that such an exercise could be included into specific conditioning programs for ACM preparedness in combat pilots.

Although this study did not directly investigate the usefulness of specific neck exercises in preventing neck injury in pilot populations, it is logical that the findings from this study, in addition to other relevant studies, should form the basis of properly designed randomized control trials in the above-mentioned specific pilot populations. “Specific” and “intensive” neck conditioning exercises have been proposed to be important for increasing neck strength in combat pilots and possibly preventing neck injury (7). Since the head positions adopted by combat pilots are known to be both uniaxial as well as bi- and tri-axial (19), the exercises used in this study may lack the specificity in certain ACM related head positions, especially Check-6, which has been linked to neck injury (7,19). There are, however, few exercises that specifically target bi-axial and triaxial movement of the neck in-flight. This may be a direction for future research.

Periodization of exercise by manipulating acute training variables such as exercise loading (intensity) and volume, are reported to be highly effective in increasing muscular strength in men (29). The results from this study suggest there exists a continuum of exercise intensity for the modalities examined. The lower muscle activation levels recorded for elastic band when compared with the resistance machine modality suggest that this modality of exercise could be useful for initial training of muscular strength and/or strength endurance (29) or rehabilitation from $+G_z$ neck injury. Conversely, neck muscle activations recorded from both the 70% and 90% resistance machine modalities were above those values recorded at $+5\ G_z$ in all neck muscles examined except SCM (Fig. 1). Such exercises could be useful as overload intensities, to increase neck strength above that experienced in flight. Conditioning of muscle based on overloading intensity has been shown to elicit significant increases in muscle strength in the leg flexor and extensor muscles (9) and such heavy loads are recommended to optimize gains in maximal strength (29). However, including these intensities into a neck conditioning program for combat pilots should be done with care as stresses placed on the passive structures of the cervical spine such as bone, intervertebral disks, and ligaments are unknown when such loads are applied. Further, decreases in muscle function have been reported immediately, and up to 33 h post-exercise, in the leg extensors with the application of such overload (22). Thus, these intensities should be limited to trainee pilots not in the high $+G_z$ phase of their training, as these exercises may diminish the ability of their neck muscles to withstand the high loads of high $+G_z$ ACM. Combat ready pilots should also be aware of this issue when performing such neck exercises during a maintenance phase of training.

There are several possible limitations of this study. First, we used two dissimilar subject cohorts; however, we believe this approach is acceptable as the pilot cohorts were of similar age and stature to the non-pilots, and neck muscle strength has been shown not to differ significantly between pilots and non-pilots (25). Second, we did not have the EMG data blindly assessed by an external assessor; however, we believe it is difficult to bias the data when automated analysis procedures such as those reported in this paper are used. Third, the dependent variable in this investigation was normalized neck muscle activation recorded by surface EMG. The limitations of this procedure are acknowledged, however, we were unable to use more invasive techniques such as fine wire and needle EMG because of the inherent ethical limitations, and the possibility of electrode displacement during combinations of high $+G_z$ ACM and free neck movement. Further, we have previously found surface EMG to be just as, if not more, reliable within-trial than intramuscular EMG in healthy controls (6) and surface EMG has been used in previous studies of this nature and the measuring technique has been shown to be reliable and useful in comparisons between individuals and muscles (11,18,27). Finally, we could have added more control to the experimental design by performing a similar study in a flight simulator, however, we chose to perform this study in real conditions to improve the study’s ecological validity.

Conclusions

Results from this study show that neck muscle activation levels recorded during some specific neck exercises fall within the range of neck muscle activations recorded when combat pilots perform ACM. The resistance machine modality has the potential to overload the neck muscles in comparison to ACM, however, the mechanical load on the passive structures of the cervical spine remains unknown in these exercises. Therefore, if added as part of a neck strengthening routine this would need to be done with care. The reported exercise modalities and intensities examined in this study provide a continuum of exercise training for specific neck strengthening in combat pilots.

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