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Neck loading in high performance combat pilots during aerial combat manoeuvres and specific neck strengthening exercises

Kevin J. Netto
Edith Cowan University

NECK LOADING IN HIGH PERFORMANCE COMBAT PILOTS DURING AERIAL COMBAT MANOEUVRES AND SPECIFIC NECK STRENGTHENING EXERCISES

Kevin J. Netto
BSc (Hon), Dip MechEng

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Faculty of Computing, Health and Science
Edith Cowan University

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

Background: Neck pain and injury is a common occurrence in high performance combat pilots (HPCP) around the world. The cause of this has been attributed to exposure to the unavoidable high mechanical loading related to the neck being positioned in non-neutral head postures whilst being exposed to moderate to high +Gz levels. Specific neck conditioning exercises have been proposed as being a possible method to decrease the incidence of neck pain and injury in this population. However, there has been sparsely published research examining the suitability of selected exercises for HPCP who participate in regular aerial combat manoeuvres (ACM).

Objective: The overall aim of this doctoral investigation was to examine the possible suitability of selected specific neck strengthening exercises in preventing and rehabilitating neck injuries sustained by HPCP during moderate to high +Gz ACM. This was investigated by conducting four inter-linked studies.

Methods: Participants in this study included healthy, young subjects (5 males) (Studies 1 and 3), (8 males) (Study 4) and operationally active pilots (6 males) (Study 2). In Study 1, the reliability of field and laboratory methods in attaining a sub-maximal and maximal voluntary isometric contraction (MVIC) of the neck and shoulder muscles for the purpose of EMG data normalisation was investigated. Study 2 examined in-flight neck and shoulder muscle EMG in addition to quantifying head kinematics during selected ACM in HPCP. These data were collected for two reasons; firstly, to provide a description of mechanical load of the neck and secondly, to be used as input into a commercially available graphically based EMG-driven musculoskeletal model of the cervical spine. Study 3 was undertaken to examine the validity of the abovementioned neck model. Specifically, subject-specific data such as neck muscle morphometry derived from MRI and muscle activation data from the deep neck muscles were collected and implemented into the model. The model's output was compared to neck torque output collected from a dynamometer. In Study 4, neck and shoulder muscle activation recorded during specific neck strengthening exercises were compared to neck and shoulder muscle EMG previously measured in-flight in Study 2.

Results: Study 1 showed that a reliable reference EMG signal could be obtained from the neck muscles for the purpose of normalisation in both field and laboratory studies.

Results from Study 2 illustrated high levels of neck muscle activation and co-contraction due to high +Gz, and head postures close to end-range of the cervical spine when HPCP performed ACM. Study 3 revealed that the musculoskeletal model of the cervical spine was not sufficiently valid at this stage to answer the questions posed in this thesis related to loading of the passive structures of the cervical spine in both ACM and specific neck strengthening exercises. Consequently, EMG was chosen as the appropriate tool to investigate neck loading in this investigation. Results from the final study showed that neck muscle activation levels recorded during some specific neck exercises fall within the range of neck muscle activations recorded when HPCP perform ACM. The reported exercise modalities and intensities examined also provided a continuum of exercise training for specific neck strengthening.

Conclusion: This series of studies showed high levels of neck muscle activation and co-contraction due to high +Gz, and head postures close to end-range of the cervical spine are present when HPCP performed ACM. Also, the selected specific neck strengthening exercises chosen in this investigation are suitable for implementation to neck strengthening regimes for elevated +Gz exposure. Further investigation is however needed in neck strengthening studies that would implement these findings into this population.

DECLARATION

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CHAPTER 1

INTRODUCTION

Neck pain and injury is a worldwide phenomenon afflicting populations regardless of geographical locality, culture, economic status and age (13, 25). The incidence of this problem however, is reported to be greater in modernised, western society with the point prevalence of neck pain in the adult population being reported to be between 5.9-22.2% and the lifetime prevalence ranging from 14-71% (25, 28). The economic cost of spinal pain (neck pain and low back pain) has been estimated at nearly 1% of an industrialised country's gross national produce (GNP) with an estimated 4% of the national workforce sick-listed or awarded temporary or permanent disability because of the affliction (31). Further, when neck pain is considered in isolation, estimates of US$686 million per year or 1% of an industrialised country's health care spending have been reported (9). Surprisingly, when one delves into the scientific literature, the comparative amount of inquiry pertaining to the pathomechanics, prevention and rehabilitation of spinal pain strongly favours low back pain, whereas injury to the neck and cervical spine is a relatively new and moderately researched area.

Neck injury has been classified by severity and compromise of the structures in the cervical spine (8, 18) as well as by origin. For example, structural compromise of the spinal column with corresponding spinal cord injury has been classified as a major injury (18). Conversely, neck injuries that do not involve vertebral fracture are usually defined as minor (8). The most widely researched area of neck injury is whiplash in rear-impact automobile accidents. This may be due to the large compensation claims associated with such an injury in addition to the prevalence of 4.2 per 1000 inhabitants being reported (63). In comparison, neck injury sustained in occupational settings has received relatively less investigation (34, 50). An unusual, but nonetheless important area of occupational neck injury is the high prevalence of neck injury sustained by high performance combat pilots (HPCP) who perform aerial combat manoeuvres (ACM) with reports of up to 90% incidence common in the aviation medicine literature (22, 46). These occupational injuries are unique in that loads on the cervical spine and surrounding musculature that HPCP typically experience cannot be replicated in land-

based occupational settings (27). Thus, there is very little that is understood about the mechanisms behind these injuries as well as how to prevent them. The following sections review the literature related to a number of key issues pertaining to the etiology and possible prevention of neck injuries in HPCP. Specifically, these sections are as follows:-

- An overview of the mechanical etiology of neck injuries and electromyography (EMG) as a methodology to investigate them.
- An overview of neck injury in HPCP
- The potential of musculoskeletal modelling as a method to further the understanding of neck injury with potential application to HPCP.
- Strengthening the neck musculature as a method of injury prevention in HPCP.

These sections are then followed by an overview of the doctoral investigation with specific research questions being outlined for each of the studies comprising the thesis.

The Mechanical Etiology of Neck Injury

The human head-cervical spine complex can be thought of as a flexible link column with a large mass at its end. The flexible link column comprises of seven cervical vertebrae (C1 to C7). The mass at the end of the column, the head, is approximately 7% of an adult's body weight and therefore tends to exacerbate stresses in the system (68). Stabilisation of the head/neck complex is created by three sub-systems; they being: the passive sub-system (vertebrae, discs and ligaments), the active sub-system (muscles and tendons surrounding the spinal column) and the neural sub-system (nerves and central nervous system) (51). These sub-systems provide stability as well as mobility in addition to allowing attenuation of shock loads and stresses to the whole complex (68). More than 20 pairs of muscles cross the joints of the cervical spine and it has been estimated that the neck musculature provides approximately 80% of the mechanical torque requirements with the remaining 20% being contributed by the

passive tissue (36, 52). A brief summary of the functions of a number of the muscles in the cervical spine are given in Table 1.

Table 1

Brief Summary of Major Neck Muscle Functions (Adapted from Coakwell et al. (17))

Flexion	**Extension**	**Lateral Bending**	**Rotation**
Sternocleidomastoid	Splenius Capitis	Ipsilateral Sternocleidomastoid	Ipsilateral Splenius Capitis
Longus Capitis	Semispinalis Capitis	Ipsilateral Splenius Capitis	Ipsilateral Levator Scapulae
Lonus Colli	Levator Scapulae	Ipsilateral Semispinalis Capitis	Ipsilateral Semipinalis Capitis
	Longissimus Capitis		Contralateral Sternocleidomastoid
			Contralateral Semipinalis Capitis

The neck may be susceptible to varying severity of injury; for example, major injuries where the structure of the cervical spine has been compromised and neurological or spinal cord damage has occurred, to relatively minor injuries, where essentially the soft tissue surrounding and supporting the cervical spine has been affected (8, 18).

Most neck injury results in some form of neck pain or disease with management traditionally based upon a biomedical model. Engel (23) proposed a biopsychosocial model to further research and understanding of the underlying mechanism to disease. This model has been recently acknowledged and adopted by researchers investigating neck injury (1, 6, 24, 37, 55, 59, 63). Risk factors pertaining to the psychosocial aspect of the model in terms of neck injury have been identified and they include job satisfaction levels, work stress, control over work, social support, to name a few (1, 6).

In terms of the bio aspect of the model, risk factors such posture, prolonged load, muscle activation and co-activation have been linked to neck injury (24, 37, 62).

With the trend in society towards litigation resulting from accident-induced neck pain and disability, soft tissue injuries of the cervical spine are often associated with insurance claims. Hence, the most often researched neck injuries are whiplash associated disorders, resulting from mechanical overloading of tissue from automobile accidents (8, 64). These injuries are usually attributed to high-load, short-duration mechanical loading patterns.

Modern work-related activities place prolonged demands on the neck and thus cause a variety of injuries. This subset of neck injury has been termed work-related musculoskeletal disorders (59). Such disorders have a high impact on modern society, with approximately 25% of all sick-leave taken in the work place being due to such problems (34, 50). Workers who perform occupational tasks that involve prolonged static postures such as dental work, nursing, sitting in front of video display units, sewing machine operating and computer aided designing typically report some form of neck or shoulder pain (50, 59) and have been associated with tension neck syndrome or myalgia (34). The mechanical etiology of these low-load, long-duration disorders clearly differs from that of whiplash associated disorders and the appearance of neck pain has been attributed to an increased demand on the smaller muscle groups of the neck (38, 62).

Electromyography of neck muscles

Electromyography (EMG) has been used as a tool to investigate the function of muscle in the cervical spine. EMG has been used in studies examining the functional demands of various occupational tasks, as a predictor of joint torque and muscle load, and as input to musculoskeletal models to measure joint moments and individual muscle load (62). In most EMG studies, raw signals are normalised to a maximal voluntary isometric contraction (MVIC), allowing comparisons between conditions and/or subjects (15, 38, 40, 45).

Surface EMG is commonly used to record muscle activation of the neck. However, this technique may be prone to crosstalk as the musculature in the neck is quite complex and a number of muscles overlay each other (62). As such, intramuscular

EMG has been used on occasion to investigate neck muscle function (7, 26). This approach is invasive as it involves inserting fine-wire electrodes into the deep muscles of the neck. Typically, these investigations are conducted in laboratory settings because of the invasiveness of the procedure and therefore exclude this method being used in field-based studies.

Surface EMG recordings have been used to investigate neck muscle activation in prolonged static work. These studies have shown that even if neck muscle activation is relatively small (5-10% MVIC), this may still cause neck pain (62). The next section in this review specifically details neck injury in HPCP. The mechanism of these injuries could be considered as an example of a moderate-load, moderate-duration injury and thus differs from both the high-load short-duration and low load–long duration neck injury mechanisms.

Key points

- The human neck is a complex system of muscle, bone, joints and connective tissue. Neck muscles predominately provide head stabilisation demands.
- The neck is highly susceptible to injury in various occupational tasks due to its unique biomechanical arrangement.
- A bio-psycho-social model of neck pain is suggested however, some elements in the model may be more dominant in specific situations.
- Electromyography (EMG) is routinely used to investigate the mechanical etiology of neck injury in occupational tasks.

Neck Injuries in High Performance Combat Pilots

High performance combat pilots (HPCP) are a unique occupational group. They routinely operate in a high gravitational force environment where they are expected to control expensive and highly complex instrumentation in order to successfully manoeuvre their aircraft. Gravitational force, which is measured in multiples of force due to gravity, is the result of accelerating (+Gz) and decelerating (-Gz) manoeuvres, which are common in aerial combat. Both acute and chronic neck pain is a common

complaint of HPCP (22, 46), often resulting in lost workdays and reduced functional performance in high +Gz situations (22, 29, 35). Spinal pathology (which may lead to neck pain and related disability) such as fractures of the cervical vertebrae, stenosis of the spinal canal, cervical disc prolapsed and premature spinal degeneration have all been attributed to prolonged exposure to high +Gz (30, 32). These spinal abnormalities may require surgery to rectify them and they may restrict or prohibit HPCP furthering their flying careers (4, 30, 32).

Epidemiology, case studies and radiological evidence

High +Gz induced neck injuries are common in pilots who fly high performance combat aircraft (46). In separate studies of American Navy and Air Force HPCP, 74% of Navy HPCP and 50.6% of Air Force HPCP reported symptoms of +Gz induced neck pain. Further, 37.9% of Finnish student fighter pilots and 89.1% of a group of Japanese F-15 pilots reported some form of +Gz induced neck pain (46). In a survey of HPCP and non-HPCP from the American Air Force, Drew (22) found that 73% of HPCP and 58% of non-HPCP (transport pilots) suffered from neck pain. It was reported that HPCP suffered from neck pain directly after, or shortly after, performing high +Gz force manoeuvres. The results of this study were quite alarming as the respondents were relatively young (mean age = 32.4 yrs) and led healthy and active lifestyles.

Andersen (4) detailed an episode where a flight surgeon flying in the rear seat of an F-16 B sustained serious cervical spine injuries during a sudden exposure to +8 Gz. The incident occurred when turning his head maximally to the left and he was unprepared for the sudden high +Gz manoeuvre. Clinical examination and radiographs suggested that he had sustained a compression fracture of C6 as well as ligamentous injury at the C5/6 level and has been since left permanently injured from the incident. Hämäläinen and associates (30) chronicled reports of two HPCPs who suffered serious neck injury after an acute exposure to high +Gz forces (typically +6.5 Gz). Both pilots had suffered from prolonged +Gz flight-related neck soreness prior to the acute episode. Radiographs of the first pilot showed spondylosis and posterior osteophytosis of the C5, C6 and C7 vertebrae. MRI investigation showed a prolapsed disc at C6/7 and a general narrowing of the spinal canal from C5 to C7. The second pilot suffered narrowing of the disc space at C4/5 and C6/7 as well as spondylosis and spondylarthrosis of the same regions. Examinations conducted six-months post-trauma revealed medulla

compression. Although both pilots made successful recoveries from their injuries, neither pilot is flying high performance aircraft and both had been set an upper level of +4 Gz during all flights. From these studies it is clear that damage to the cervical spine in the form of radiological abnormalities occurred as a result of acute exposure to +Gz forces.

Hendriksen and Holewijn (32) conducted a longitudinal study of the cervical spine in 316 F-16 pilots. A corresponding group of non-high performance pilots were used as controls. Two sets of x-ray films from each subject were taken at least 150 flying hours apart (or two years real time). The radiographs showed significantly increased osteophytic spurring at C4/5 and C6/7 level amongst the F-16 pilots when compared to the control group. Arthrosis deformans was also prevalent in the F-16 group when compared to the control group. The authors did not study or report the prevalence of neck pain among the subjects but they did suggest that frequent exposure to +Gz may cause degeneration of the cervical spine.

Head kinematics during aerial combat manoeuvres

Studies of HPCP have reported an aggravation of neck pain when certain head postures are adopted during aerial combat manoeuvres (ACM) (4, 22, 27, 46). These head positions included 'Checking-6' (combined rotation and extension of the neck to check astern for aircraft, see Figure 1) and executing moderate to high +Gz manoeuvres (between +3 Gz and +6 Gz) when the head is in a non-neutral position. This hypothesised relationship between head posture in flight and neck pain has lead researchers to examine head kinematics collected from a rearward-facing camera located in the cockpit while HPCP perform ACM (27, 33). Results from these studies show HPCP typically adopt non-neutral postures during ACM such as extension, and combined movements such as extension and axial rotation and extension and lateral bending. Considering temporal analysis of these non-neutral postures, it was found that such non-neutral head postures were adopted for approximately 67% of a four-minute bout of ACM (27). It has also been noted that more extreme head positions were adopted with increased +Gz levels (27).

When quantifying the above non-neutral head postures, values in extension of no greater than 40° (33) and over 61° (27) were reported. It could be hypothesised that the

latter study described head postures that resulted in the cervical spine being positioned in the so-called "elastic zone" (53). The elastic zone is where passive structures of the cervical spine (ie. vertebrae, spinal ligaments and intervertebral disks) are thought to develop high reactive forces to spinal movement suggesting that if the musculature of the neck is unable to withstand the high loads of hypergravity, these structures may be injured. It should be mentioned that the measures of three-dimensional head kinematics were estimated from a single camera in both studies, rather than the more often used multiple camera approach. This may have lead to inaccurate estimates of head posture and thus should be considered as an approximation only.

Figure 1. HPCP adopting a 'check-6' head posture by a combined rotation and extension of the neck to check astern.

Neck muscle activation during aerial combat manoeuvres

With the miniaturisation of EMG data collection devices, a number of researchers have been able to collect in-flight recordings of neck muscle activation from various body sites. Hämäläinen and Vanharanta (29) collected in-flight muscle activation levels from the cervical erector spinae in 10 experienced HPCP. Subjects did not pilot the aircraft but sat in the front seat and performed a number of head movements while the aircraft engaged in ACM to a pre-determined +Gz level. An increase in muscular activation (as determined by normalised linear envelope data) with

increased +Gz was reported (mean +4Gz = 15.7% MVIC, mean +7Gz = 37.9% MVIC). Further, much higher levels of neck muscle activation were noted when pilots twisted and extended their neck during specific ACM (up to 100% of MVIC).

Oksa and co-workers (49) used similar data collection and processing methods as Hämäläinen and Vanharanta (29) to examine in-flight muscle activation levels from the thigh, abdomen, back and lateral neck (Sternocleidomastoid). In this study, six Finnish Air Force HPCP performed three minutes of ACM with more than 30% of the flight time spent over +3 Gz and a maximum of +7 Gz reached twice during the flights. Relatively low levels of neck muscle activation were reported in all muscles sampled except for the back and lateral neck regions (18.7% MVIC). Alarmingly high peak values (up to 257% MVIC lasting for approximately 8 seconds) were also reported for the lateral neck. These extremely high values of neck muscle activation may need to be viewed with caution as the researchers may not have obtained a true maximum for EMG normalisation purposes, therefore artificially inflating the reported muscle activation levels.

In this and other field-base studies, the methods to elicit an MVIC have tended to be much less complex and subsequently more portable when compared to laboratory-based, dynamometry-based approaches (38, 45). Examples of field-based set-ups have included a leather cuff fitted securely around the forehead and linked to a chain fastened to a wall, in addition to manually applied resistance to elicit an MVIC (47, 49, 57). There is however, a paucity of reliability data for the various methods of eliciting an MVIC in EMG analysis of the neck muscles (62).

Head kinematics and neck muscle activation levels in HPCP during ACM were also examined by Green and Brown (27). EMG data collected while HPCP performed ACM was collected bilaterally from the sternocleidomastoid and cervical erector spinae muscles from five male HPCP and one male aircrew. Levels of muscle activation (Normalised Root Mean Square data) in the cervical erector spinae were somewhat linearly (r^2 = 0.73) related to +Gz levels. It was also noted that extreme head positions were typically adopted with increased +Gz levels. Although this was one of the few studies to include synchronised recordings of head position and neck muscle EMG, the accuracy and reliability of the data is questionable as the three-dimensional head kinematics were again estimated from a single camera. Head angles were broadly

classified into three groups (small: 5° to 30°, moderate: 31° to 60° and large: 61° to end-of-range) which further questioned the validity of the methodology.

From the above study neck muscle strengthening programs were advocated to prevent injury in susceptible areas, namely the neck and shoulders. This concept has also received support from others who hypothesised that the best strategy to prevent neck injury from prolonged moderate to high +Gz flying and non-neutral head postures was to strengthen the neck (17, 27, 29, 35)

Key points

- There is a high incidence of neck pain evident in HPCP as they are routinely exposed to a moderate to high +Gz environment when performing ACM.
- The neck pain literature suggests the adoption of a bio-psycho-social model, however, HPCP are highly motivated individuals and this suggests a mechanical etiology of neck pain.
- The head is commonly positioned in non-neutral postures during flight.
- To stabilise the head during moderate to high +Gz flight, high levels of neck muscle activation are required.
- Few studies have examined the reliability of neck muscle EMG normalisation methods. This is especially the case in field-based studies.
- The exact pathomechanics of the neck injury in HPCP during ACM are unknown. More data is required to precisely measure head postures with respect to end range and muscle co-activation.
- Strengthening the neck musculature has been suggested by several authors as an appropriate method of prevention of neck injury in HPCP.

Musculoskeletal Modelling of the Neck

To formulate intervention strategies for injuries sustained during human movement, it is vital that the mechanisms of these injuries be first thoroughly examined

and understood (48). With reference to research pertaining to neck injury, EMG can clearly provide valuable insight into the function of the various neck muscles, their level of activation and state of fatigue during various actions (62). However, EMG cannot provide force-time histories for loading on passive tissue (bone, disc and ligament) which may contribute towards the etiology of neck pain. Thus, a number of approaches have been used to estimate such forces acting on the cervical spine, to heighten the understanding of specific injury mechanisms and these have included; creating a physical model (fabricated models of the neck), *in-vitro* and *in-vivo* investigation in both humans and animals, and the use of mathematical, computational and musculoskeletal models. These models have provided insight into the workings of the cervical spine and have also provided diagnostic guidelines for injury and instability (52).

In musculoskeletal models, there are many biological systems that must be represented by mathematical equations. In 1939, Hill proposed a simple and precise mathematical representation of human muscle. This model consisted of three elements; a contractile element under neuromuscular control and two spring-like elastic elements, one in series and one in parallel. This three-component model has been used almost exclusively in various movement simulations and is considered the most practical for human movement situations (10). The Hill muscle-model relies on the input of muscle activation levels and morphometric characteristics to scale generic muscle force-length and force-velocity curves, as such computing individual muscle force-time histories and net torque histories about specific joints (10, 71). There have been a number of different methods developed to facilitate the input of muscle activation. These approaches consist of optimisation, forward dynamics, EMG and neural networks (21). Muscle morphometry for these models has usually been derived from cadaveric specimens (20, 66), anatomical text and drawings (15, 45) and radiographs and images (43, 44). The methods of modelling are outlined with reference to both general and specific examples to this thesis in the following sections.

The usefulness of most musculoskeletal models is dependant upon the model's ability to accurately predict natural, biological phenomenon (21). Since direct measures of muscle force *in-vivo* is impossible, a number of different methods have been utilised to judge the validity of the model's output. Generally, when EMG has been used as input, an external summation of torque about the joint in question is measured synchronously (71). This external torque measure is used as a benchmark for the model

to predict. Also, optimisation procedures use this value to tune the model for better predictions (10).

Optimisation models of the neck

Due to the indeterminacy issues related with modelling human joints, methods had to be constructed to allow models to solve these functions and predict forces, thus resulting in a number of researchers using an optimisation method of driving the muscle model (21). Moroney et al. (45) modelled fourteen pairs of muscles in the cervical spine that cross the C4 vertebrae and the cross sectional area of these muscles were gathered from scaled drawings of the neck at this level. A double linear programming optimisation scheme (DOPT) was used to calculate muscle contraction forces by minimising muscle forces to attain equilibrium of the system, as well as minimising compression loads on the spine. To validate the model the authors collected surface EMG while subjects performed isometric contractions in the neutral posture. High levels of linear correlation (>0.82) between muscle force and EMG were reported for the anterior muscles of the neck in flexion however, a lower correlation (<0.75) existed for muscle forces predicted by the model for posterior neck muscles in extension. Critically, the commonly held assumption made in modelling that minimal force was being generated by the antagonists was proved incorrect by some of their EMG readings. Also, the assumption of linearity between EMG and muscle moments made by the authors is dubious thus questioning the model's validity. It was concluded that with the range of correlation (between 0.33 to 0.85), the model was able to approximate neck muscle contraction forces in quasi-static situations.

Snijders, Hoek van Dijke and Roosch (61) modelled the muscle forces and joint moments in the cervical spine during high +Gz ACM. They developed a kinematic model of the cervical spine and used optimisation techniques to determine muscular forces and joint moments in various static postures typical in ACM. The kinematic model of the head and neck consisted of an eight-link chain with six degrees of freedom in each link. The model was simplified by a number of assumptions. Firstly, the axes of rotation were assumed to be located in the middle of each joint. Secondly, C3 to C7 were modelled as a single linked unit rather than as separate vertebrae. Thirdly, ligament and connective tissue forces in the spine from C2 to C7 were not included in the model. Finally, the head relative to the cervical vertebrae was modelled from

anthropometric data and physiological limits of motions for an average adult male. Criteria such as cross sectional area of muscle and the related moment arm length, both important contributors to head stabilisation via torque generation, were used to select the muscles they modelled. These data as well as the muscle origins and insertions were gathered from anthropometric literature and anatomical texts. An optimisation algorithm calculated muscle and joint forces for every combination of three muscles in the neck (it was assumed that only three muscle forces were sufficient to stabilise the head). The input parameters for the model were the weight of the head, acceleration forces (Gz) and the weight of a helmet.

It could be considered that the model of Snijders and co-workers' was an oversimplification of reality. The optimisation calculations led to a minimisation of joint reaction forces as synergistic and stabilisation forces were not incorporated. This could prove unrealistic during ACM when it is possible that a number of muscles are used to stabilise the head in the moderate to high +Gz environment. In this model, calculated muscle forces were shown to be very sensitive to the muscle morphometric data used. Specifically, deviation of 10% in muscle morphometry caused a 60% change in muscle force. Regardless of this the authors obtained indications that the magnitude of forces from the model were correct but it was not outlined why this was the case.

EMG-driven models

From the previous section, it is clear that the optimisation method of driving musculoskeletal models is physiologically questionable as the assumption is made that agonistic muscle forces are maximised and antagonistic co-contraction is minimised. Consequently, researchers have proposed a number of solutions to deal with this problem. For example, to estimate spinal loading at the L4-L5 joint during lifting tasks, McGill and Norman (42) developed an anatomically accurate three-dimensional dynamic model of the lumbar spine that used the level of muscle activation derived from EMG recordings to drive the model.

Choi and Vanderby (15) used this method to model 14 pairs of cervical muscles to calculated muscle forces and spinal loads at C4/C5 level during various isometric head movements. Anatomical data were derived from cross-sectional drawings of the

neck musculature (45) and EMG data were collected from eight sites around C4/C5 level and were normalised to MVIC. These sites were:

- Anterior: Approximately midway between anterior midline and anterior border of sternocleidomastoid,
- Anterolateral: Approximately midway between anterior border and posterior border of sternocleidomastoid,
- Posterolateral: Approximately midway between posterior border of sternocleidomastoid and anterior border of upper trapezius,
- Posterior: Approximately. midway between anterior border of upper trapezius and posterior midline.

To compare various modelling approaches the authors then developed two additional models of the neck namely; the DOPT similar to that outlined by Moroney et al. (45) and an EMG-assisted optimisation method (EMGAO), adapted from the lumbar spine model of Cholewicki et al's (16). Results from both the EMG-driven and the EMGAO models again showed that the DOPT assumption was possibly too simplistic as significant muscle activation levels were detected in the antagonists. While the DOPT method nullified forces in the flexors during extension, extensors during flexion and the contralateral muscles during lateral flexion, the EMG and EMGAO methods showed activity in all muscles. This subsequently showed that joint forces from DOPT were significantly lower than EMG and EMGAO models. It was concluded that the EMG-driven and EMGAO methods of modelling predicted muscle force patterns more accurately than the DOPT model.

Graphically-based musculoskeletal models

One of the greatest limitations towards the use and acceptance of musculoskeletal models is that these models are typically developed in high-level computer programming environments, thus they remain inside the creator's laboratory environment. Delp and Loan (19) utilised the improved animation power of computers to address this matter. They developed a commercially available software package, Software for Interactive Musculoskeletal Modelling (SIMM, Musculographics Inc, Santa Rosa, CA), to assist researchers in modelling various parts of the human body.

The software package is to be general enough for any musculoskeletal structure to be modelled, allows the user the flexibility to potentially validate the model and is sufficiently interactive that alterations of models can be made quickly and without intensive programming.

The SIMM software package used graphical representations of bones and muscle allows kinematics of joints to be created and manipulated. Muscle is modelled as geometrical lines with five input parameters scaling a generic Hill-type muscle-tendon actuator (19). To allow calculation of neck muscle forces and moment generating capacities Vasavada, Li and Delp (66) developed the SIMM neck model. In this model, 18 distinct neck muscles were functionally divided into separate sub-volumes providing anatomical accuracy however, whilst this may seem a distinct advantage, it is still difficult to accurately drive these muscles with physiologically meaningful muscle activation values due to their inaccessibility. Specific neck muscle morphometric data such as physiological cross sectional area (PCSA), optimal fascicle length and pennation angle were also integrated into the model. These data were generated in the study of Kamibayashi and Richmond (36) who dissected the neck muscles from ten cadavers (3 female, 7 male, age 66-92 years). These methods of obtaining data from cadavers can be criticised as being a misrepresentation of the population where the model will be used. Delp et al. (20) have suggested a hybrid approach of combining cadaveric study with modern imaging techniques, providing for the most accurate representation of measures.

To assist in validating the Vasavada et al (66) model, a sensitivity analysis was conducted examining the effect of change of muscle physiological cross-sectional area (PSCA), pennation angle, muscle force constant and position of the axis of rotation. The model was highly influenced by variations in muscle PCSA (1 SD change = 25-32% change in moments generated) however, muscle pennation angle was not as sensitive (< 5% change in moments generated when angle set to 0). Also, the constant used to calculate muscle force generating capacity from PCSA ($35 N/cm^2$) was lower than values such as $55 N/cm^2$ that have been utilised in other models (10). This constant was deemed appropriate as the morphometric data was obtained from 68-80 year old fresh cadavers. Similarly, changes of one SD in the position of the axis of rotation data (3) have resulted in large changes in flexion moments (20%), little for extension moments (5%) and minimal change in axial rotation and lateral bending moments (1%).

Although the model created by Vasavada and associates has not been directly validated by comparison of generated torque values to criterion values measured by a dynamometer, prediction of extension and axial rotation net moments were reported to be similar to other studies (15, 41). However, flexion moments were much lower than those reported by these same studies. The authors attributed this difference to the choice of the axis of rotation during flexion movements. Also, it was noted that there may have been contribution to flexion moments by muscles that were not modelled, such as infrahyoid and platysma. It should be noted that when these net moments were calculated, muscle activation levels were assumed to be 100%. This is a major assumption as it is clear that neck muscles (in fact any muscle) are activated at levels ranging between 0-100% MVIC during movement and muscle contraction (67). However, it should be stated that the model has provided valuable insight into the basic mechanics of the cervical spine.

Key points

- Musculoskeletal models may be useful in understanding the pathomechanics of neck injury.

- Advances in computing power have allowed the creation of graphically based modelling software to aid the modelling process and increase flexibility of such models.

- A neck model using such software has been created (Vasavada et al., 1998). This model has been reported to be very sensitive to changes in muscle morphometry.

- The model has not been developed to allow the inclusion of a neuromuscular drive (ie EMG). Also, muscle morphometric data was gathered from elderly cadaveric specimens. These data might be inappropriate if the model is used to calculate muscle forces and torque histories in young people.

- Whist a cervical spine model has many potential applications; the model has not yet been validated to a set criterion.

Does Increasing Neck Strength Help in Preventing Neck Pain?

Recent studies have indicated that performing conditioning exercises specific to the neck musculature can increase neck strength and decrease neck pain (14, 69, 70). Further, specific conditioning of the neck musculature has been shown to elicit significant increases in neck muscle strength and endurance increases (2, 12). However, what is the theoretical basis of exercise prescription as a preventive intervention for neck pain? In a review of preventative interventions for neck and back pain, Linton and van Tulder (39) found exercise to be the only intervention that showed consistent positive results when compared to other interventions such as education, supports, ergonomic alterations and risk factor modifications. They postulated that exercise has the effect of:

1. Increasing strength
2. Increasing flexibility.
3. Increasing blood profusion to spinal muscles, disks and joints thereby reducing injury and facilitating repair.
4. Improved perception and tolerance of pain.

The physiological and psychological manifestations outlined in point 2, 3 and 4 have been linked with aerobic and flexibility exercises and they also lie outside the scope of this investigation. However, point 1 has a more mechanical foundation and applies directly to this study. Linton and van Tulder (39) further recommended the use of targeted strategies to specific populations in the prescription of preventative measures. Neck strengthening exercises have been used as a form of therapy for neck pain. Sarig-Bahart (56) revealed strong evidence for the use of dynamic resisted neck strengthening exercise and proprioceptive exercises in the treatment of chronic neck pain. Strong evidence was also reported for the use of mobilising exercise in the treatment of acute whiplash disorders. It was however suggested that investigations should now start to focus on the correct intensity required to elicit a training effect and how to progressively overload the neck musculature, including the use of different modalities, in order to attain a significant and rapid improvement in function and performance.

When designing neck strengthening programs, a number of considerations such as contraction direction, gender and baseline strength levels are important. Common exercise modalities used to increase neck muscle strength in a multidirectional 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. Furthermore, Thera-Band latex tubing (Hygenic Corporation, Akron, OH) is available as colour-coded bands of varying thicknesses therefore, providing different resistances and altering exercise intensity. Previous research has examined the differing resistances provided by various grades of Thera-Band (54, 65) and there seems to be subtle differences in resistive force between the colour-coded bands however, the exact difference in force is dependent upon factors such as starting length, the level of strain, rate of loading and the particular joint the Thera-band is being used to strengthen (60, 62). Although the abovementioned modalities are commonly used, there is little empirical evidence available on how changes in exercise intensity actually effect neck muscle activation. Such information is required to aid program design so that improvements in neck muscle strength can be optimised.

Neck Strengthening Exercises in HPCP

It is clear from the literature reviewed in previous sections that HPCP are exposed to high neck loads during ACM. Neck strengthening exercises have been previously suggested as being useful in both the prevention and rehabilitation of neck pain and injury in this population (5, 35, 46). Since neck muscle strength increases, but not significantly so, with +Gz exposure (11) and no significant difference in maximal neck strength between HPCP and non-HPCP exist (58) the need for HPCP to perform neck strengthening exercises to prevent neck injury has been proposed by many researchers (5, 27, 29, 32, 35)

Hamalainen and Heinijoki (32) compared increases in neck strength in a group of pilots performing dynamic neck exercises and a group of pilots performing slow, low intensity neck exercises. The study showed an increase in isometric neck strength in both groups but no change in cervical range of motion. Further, the group performing dynamic exercises had fewer workdays lost from +Gz induced neck pain. No definitive conclusion could be made from this study, as the sample size (ten in each group) was

small. It was also noted that the parts of the dynamic exercise regime, namely warm-up and stretching exercises, could have been beneficial to the pilots.

Despite the repeated suggestion for the use of neck strengthening exercises by HPCP, there has been little research conducted on the type, duration or suitability of these exercises for high +Gz ACM. However, Alricsson et al (2) reported increased neck muscle strength and endurance in 20 HPCP after undertaking a supervised neck-training program administered 3 times per week over 6-8 months. Descriptions of the actual movements and exercises were omitted from the study although it was stated that the training program consisted of 4 sets x 10 repetitions of weighted neck and shoulder exercises and thoracic exercises using rubber tubing as a resistance. No detailed reports of exercise intensity were included except that weights were increased based on strength improvements. The investigators also showed no significant changes in neck muscle strength and endurance within a second group of HPCP who were also given the same program but were not monitored as closely. The study clearly showed the usefulness of a neck strengthening program and the importance of encouragement and supervision of subjects in such training programs.

Key points

- Neck strengthening exercises have been shown to be beneficial in preventing and treating work-related musculoskeletal disorders of the neck.
- Researchers have advocated the use of specific neck strengthening exercises in the prevention of +Gz induced neck injury in HPCP.
- Further investigation is required into the use of methods behind increasing neck strength. Specifically, research investigating both modality and intensity of such exercises is an important step towards optimising strength gains.

General Overview of the Investigation

The broad aim of this doctoral investigation was to examine the suitability of specific neck strengthening exercise in preventing and rehabilitating neck injuries sustained during high +Gz ACM. The overall purpose of the thesis was investigated by

conducting four inter-linked studies. Firstly, a reliable method of neck muscle EMG normalisation was investigated. Next, in-flight neck muscle EMG and head kinematics were recorded. Thirdly, the validity of a graphically based EMG-driven musculoskeletal model of the cervical spine was examined. Lastly, neck and shoulder muscle activations recorded during specific neck strengthening exercises were compared to neck and shoulder muscle EMG previously measured in-flight. These studies allowed the suitability of these exercises for HPCP exposed to high +Gz situations to be ascertained. The specific purpose and related research questions of the four studies comprising this thesis are listed below. Figure 2 illustrates the overall flow of this doctoral investigation.

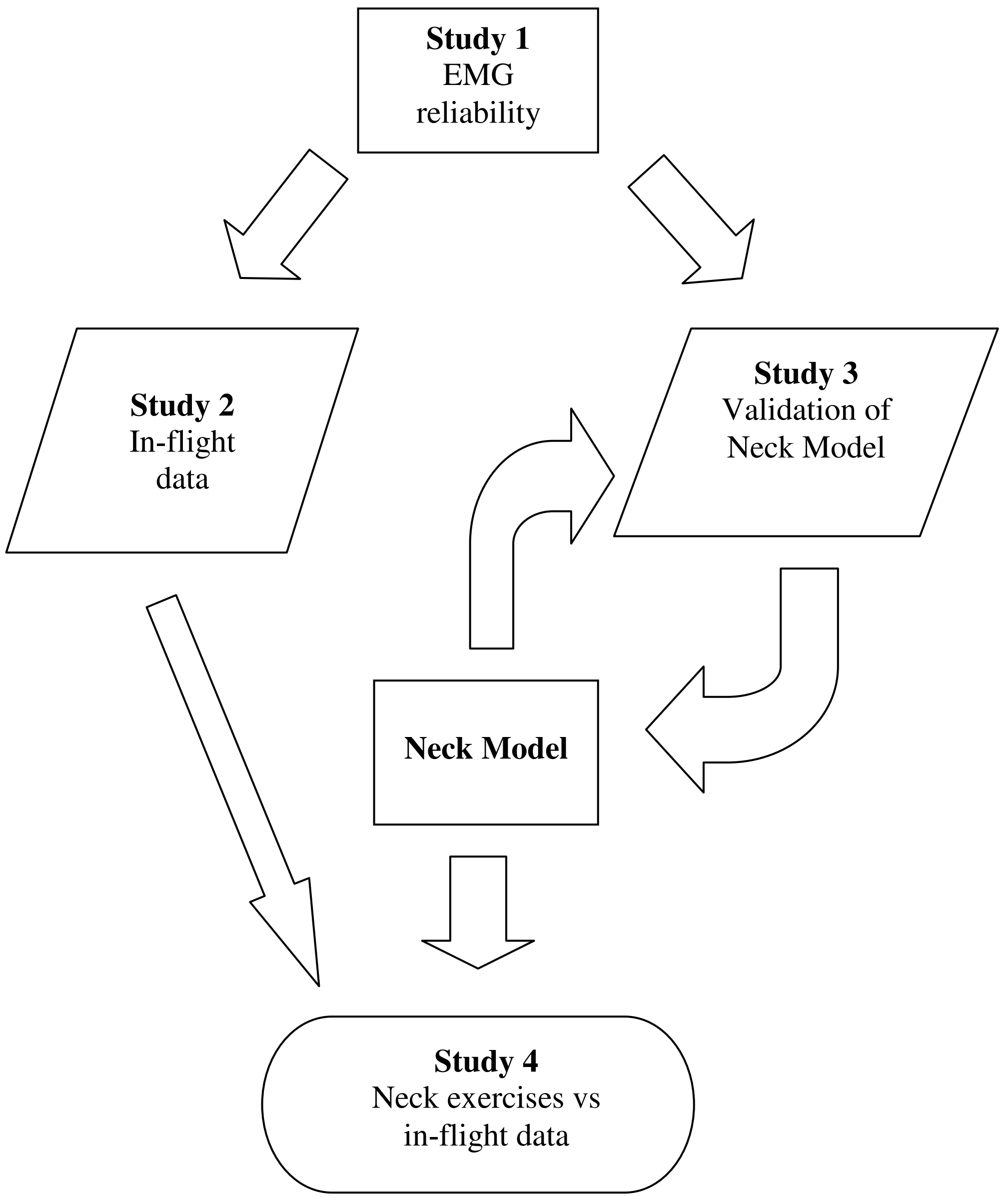

Figure 2. Overview and flow of the investigation.

Study 1

The purpose of Study 1 was to determine the best method of obtaining a reliable reference EMG signal that could be used for normalisation of EMG data collected from the neck. The normalisation process allowed the resulting signal to be utilised as input into an EMG-driven musculoskeletal model with activation levels between 0 and 100% in most tasks. The study posed the questions:

1. What is the best method of obtaining a reliable reference EMG signal that could be used for normalisation of EMG data collected from the neck?

2. Is a field based method of EMG normalisation as reliable as traditional laboratory based methods?

3. For EMG normalisation purposes, are sub-maximal normalization contractions as reliable as maximal contractions?

Study 2

The second study had a twofold purpose. Firstly, the activation of selected neck and shoulder muscles were examined 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 post-flight by asking pilots to repeat the head postures adopted in-flight. These postures were described relative to the pilot's cervical range of movement (ROM) thus allowing an improved understanding into the mechanisms of neck injury.

Study 3

Study three delved into the development and validation of a subject-specific graphically-based EMG-driven, musculoskeletal model of the cervical spine. The process involved using EMG and MRI data to validate a commercially available model, comparing predicted neck torque measures from the model with synchronised measures of neck torque from an isokinetic dynamometer. It posed the generalised question:

1. Can isometric moments be accurately predicted by an EMG-driven musculoskeletal model of the cervical spine?

Study 4

Study 4 used EMG from the neck muscles as a measuring tool for neck loads. Neck muscle EMG collected in-flight was compared to neck muscle EMG recorded during specific neck strengthening exercises. The research question posed was:

1. Do neck muscle activations generated during neck strengthening exercises approximate those experienced in-flight during ACM?

Abbreviations

ACM: Aerial combat manoeuvring, sometimes call dog-fighting. Pilot performs a series of aerobatic manoeuvres to engage the enemy in aerial warfare.

C1, C2…C7: Cervical vertebrae number 1 to 7.

Check-6: Combined rotation and extension of the neck to check astern for aircraft

EMG: Electromyography.

Gz: Forces generated by accelerations, measured in multiples of the acceleration due to gravity.

+Gz: Denotes forces that push the pilot into the seat.

-Gz: Denotes forces that push the pilot into the canopy of the aircraft.

HPCP: High performance combat pilots. Usually jet pilots flying in situation of up to +9 Gz.

LabVIEW: Graphical programming software. (Developed by National Instruments™)

MRI: Magnetic resonance imaging.

NVG: Night vision goggles.

ROM: Range of movement

SIMM: Software for interactive musculoskeletal modeling (Software package by MusculoGraphics™)

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CHAPTER 3

NECK MUSCLE ACTIVATION AND HEAD POSTURES IN COMMON HIGH PERFORMANCE AERIAL COMBAT MANOEUVRES*

Abstract

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 manoeuvres. There is still little known about the pathomechanics of these injuries. 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 post-flight with respect to end-range of the cervical spine using an electromagnetic tracking device. Mean muscle activation increased significantly with both increasing +Gz and non-neutral head postures. Check-6 at +5Gz (mean activation of all muscles = 51% MVIC) elicited significantly greater muscle activation in most muscles when compared to 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. 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 to the pathomechanics of neck injuries in high performance combat pilots.

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Introduction

Work-related musculoskeletal disorders have a high impact on modern, industrialised 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 one-year 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, 13, 14). Cervical spine pathology which may lead to pain and disability such as, fractures of the cervical vertebrae, stenosis of the spinal canal, cervical disc prolapsed and premature disc degeneration have all been attributed to prolonged exposure to high acceleration and deceleration forces whilst flying. These forces are measured in multiples of the force due to gravity (Gz) and are commonly the result of aerial combat manoeuvres (ACM) (12, 18, 22). In some cases HPCP may have their flying careers restricted or prematurely ended by neck injury (2, 14, 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 (13) while peak levels of activation of 257% MVIC have also been reported for the sternocleidomastoid at high +Gz (23) although the method of normalisation of this data may be questionable (21). These high levels of neck muscular activation have been considered to be causative of neck injury (12, 13, 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 manoeuvres with the head in a non-neutral position (18). Incidences of 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) hypothesised 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 characterised 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 hypothesised 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 post-flight by asking pilots to repeat the head postures adopted in-flight. These postures were described relative to the pilot's cervical 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 yrs, height: 1.78 ± 0.04m, weight: 82.5 ± 8.4kg, flying time: 375 ± 23 hours) and one fast jet instructor (45yrs, 1.76m, 80kg, 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 (0.8kg), G-suit (1.5kg), lightweight helmet/visor (1.2kg) (Gentex HGU-55/P

Gentex, USA), oxygen masks (0.5kg) (MEL Aviation MO3110/MO3109 MEL Aviation, UK), secumar (4.2kg) (Bernhardt Appatarabau, Germany), leg restraints (0.4kg) (Martin Baker, UK), boots and gloves.

Ethical and technical approval for the study was obtained from the Australian Defence 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. (29) 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) twin-seater single engine jet was used as the test aircraft. Synchronised 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 +1Gz, +3Gz and +5Gz) 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 whilst looking straight ahead;
- Extension – extension of the head to look through the top of the canopy;
- Turn – axial rotation of the head to look into a right turn of the aircraft;
- 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 randomised however, all head postures within a specified +Gz level were completed prior to the next +Gz level being tested. The four head postures were randomised within each +Gz level. An example of the sortie structure with the corresponding +Gz levels and head postures is outlined in Table 4.

Table 4

An Example of a Sortie Used in the Study

+Gz	**Head Posture**			
3	Extension	Turn	Check-6	Neutral
1	Check-6	Neutral	Extension	Turn
5	Turn	Extension	Neutral	Check-6

Subjects executed the sortie as instructed in the flight briefing and would initiate the desired +Gz level with an appropriate flight manoeuvre. Pilots then adopted the four head postures while continuing to keep +Gz at the desired level. Each head posture was held for approximately three seconds with the head being repositioned to neutral for three seconds before adopting the next head posture. To facilitate accurate synchronisation of EMG recordings, subjects were instructed to verbalise 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 levelled the aircraft at +1Gz and commenced a two-minute rest period to allow full physiological recovery. Each test at a specific +Gz level lasted approximately 60 seconds and the whole protocol was completed within 10 minutes. Video and audio footage allowed synchronisation 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 post flight.

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 summarised below:

- Left and Right Sternocleidomastoid (LSCM, RSCM) - 1/3 distance from the sternal notch to mastoid process, over the main muscle belly (21);

- Left and Right Levator Scapulae (LLSC, RLSC) - Midway between the posterior border of sternocleidomastoid and the anterior border of upper trapezius (21);
- Left and Right Cervical Erector Spinae (LCES, RCES) – 10mm 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 fibres (21);
- 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 fibres.

Excess body hair was removed and the area was abraded then cleaned with an alcohol swab. Pairs of 12mm diameter Ag-AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN, USA) were adhered to the skin with a 20mm centre-to-centre distance along the muscle fibre orientation. An impedance meter was then used to ensure an impedance reading of $<10k\Omega$ prior to collection. Separate ground placements for each channel were placed on the bony prominence of the clavicle. EMG signals were sampled at 1000Hz via an eight channel portable data logger (ME3000P8, Mega Electronics, Kuopio, Finland) with miniature analogue 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 take-off, subjects performed a series of maximum voluntary isometric contractions (MVICs) for the purpose of EMG data normalisation. 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 five second MVIC in a neutral posture.

Upon completion of the normalisation 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 minimise 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 take-off. 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 post-flight from the in-flight video footage, using an electromagnetic tracking device (3-Space Fastrak, Polhemus Navigation Sciences Division, Vermont, USA). The device consists of an electromagnetic source (transmitter), a systems electronic unit and two receivers (each of which have a three-dimensional coordinate system embedded) and is known to be accurate to 0.2º. The magnetic source was securely fixed to a wooden frame and this was placed 0.2m 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 however is taken into account through our data analysis methods where head postures are calculated relative to the thorax. Firstly, active range of motion (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 randomised.

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 customised LabVIEW V6.1 (National Instruments Inc., Texas, USA) program and raw EMG data were then demeaned, high-pass filtered at 15 Hz to remove any movement artefact, full wave rectified and low pass filtered at 4Hz 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-msec 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 verbalising 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 post-flight from the Fastrak were analysed in a customised LabVIEW V6.1 (National Instruments Inc., Texas, USA) program to obtain rotations of the head relative to the thorax. As the raw data output by the Fastrak was in a lateral bending (Z), flexion/extension (Y) and axial rotation (X) Cardan angle sequence, matrix algebra procedures similar to those outlined by Burnett et al. (7) were used to transform the data to a more appropriate Cardan angle sequence. The order of rotation utilised for the kinematic analysis in this study was YZX as recommended by Hof and associates (17). Maximal values for each rotation were recorded from both the ROM and in-flight head posture trials. Maximal values obtained for axial rotation and lateral bending in ROM were averaged from the maximum values obtained from left and right rotations. After data processing, only extension ROM values were used to normalise head posture data as HPCP were observed to only adopt extension as opposed to flexion in the postures examined in this study. Values from ROM were used to scale the ACM-related head posture values to allow a percentage of ROM to be obtained.

Statistics

The overall effect of +Gz and head posture on the normalised level of muscle activation was analysed 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 data set with data being judged as normally distributed ($P > 0.05$). Where a significant effect from the ANOVA was found ($P<0.05$), post-hoc comparisons were made using Tukey's "honesty significant difference" test for pair-wise comparisons. Activation of each muscle between head postures was also examined at the +5Gz 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 whether 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 post-flight (21). All statistical tests were conducted using SPSS version 14 (Chicago, IL, USA).

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 +1Gz (16% of MVIC) when compared to +3Gz (24%) and +5Gz (33%) (Figure 7). Further, average muscle activation was significantly greater ($P \leq 0.02$) for all head postures when compared to the Neutral posture (Figure 7). The Check-6 head posture elicited significantly greater muscle activation when compared to 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.

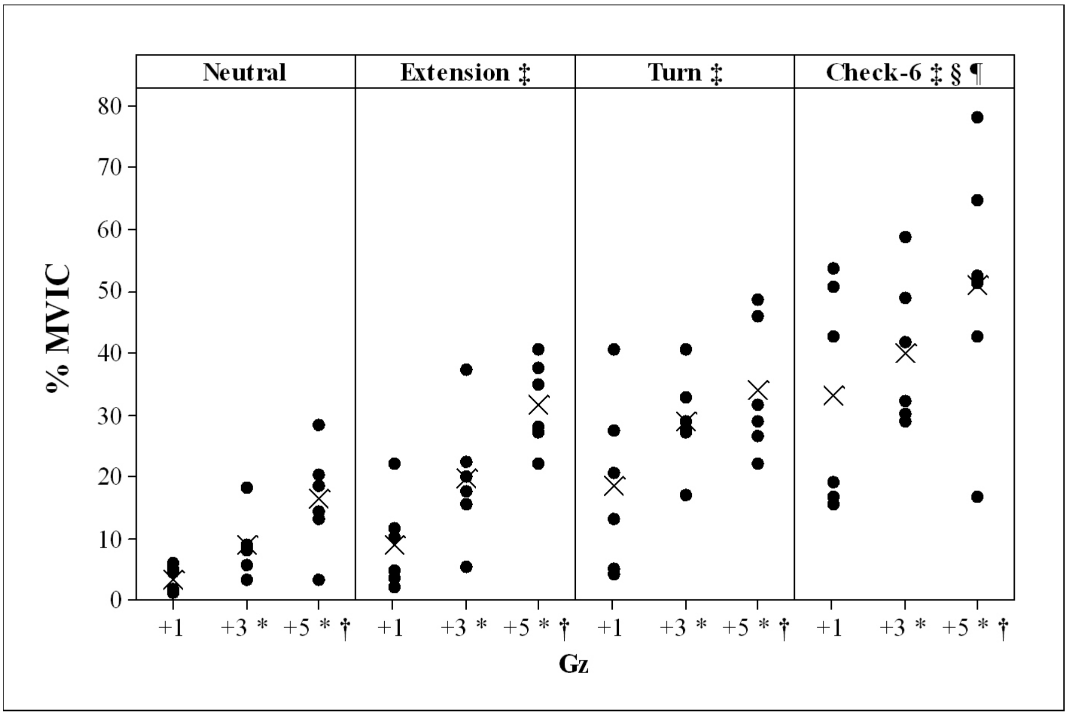

Figure 7. Normalised muscle activation across all muscles with varying +Gz level grouped by aerial combat manoeuvre-related head postures. X indicates the mean value and dots indicate individual subject data.

* significant difference when compared to +1Gz (P = 0.001).

† significant difference when compared to +3Gz (P = 0.001)

‡ significant difference when compared to Neutral (P ≤ 0.02)

§ significant difference when compared to Extension (P = 0.009)

¶ significant difference when compared to Turn (P = 0.001)

LSCM at +5Gz displayed the highest level of activation of all muscles examined (71.5% MVIC) and this occurred when the Check-6 posture was adopted (Figure 8). There were significant differences (P ≤ 0.026) evident between head postures for the level of muscle activation for all individual muscles at +5Gz with the exception of LUTR (P = 0.351). Post-hoc comparisons demonstrated that the Check-6 head posture elicited significantly higher levels of activation when compared to; Neutral (P ≤ 0.029) in all muscles except RLSC and LUTR, and Extension (P ≤ 0.021) except in RSCM, RLSC, LLSC and LUTR. Check-6 did not elicit significantly higher activations when compared to Turn (P ≥ 0.085) except in RSCM. In a majority of cases muscle activation

levels were also not significantly different when Neutral was compared to Extension ($P \geq 0.115$) except in RSCM, LSCM and RUTR. However, significant differences were noted when Neutral was compared to Turn ($P \leq 0.041$) except in RCES, RUTR, LCES and LUTR. No significant differences in muscle activation were found for any muscle when Turn was compared to Extension ($P \geq 0.027$) except in RSCM. LUTR was the only muscle not to exhibit any significant change in muscle activation ($P \geq 0.115$) 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 ($P \leq 0.029$) and these differences only occurred in the Check-6 and Turn head postures. There was however a trend towards differences between LUTR and RUTR in extension ($P < 0.09$) and turn ($P < 0.10$) head postures.

High levels of within-subject reliability were observed when post-flight estimation of in-flight head kinematic data were analysed (ICC values > 0.83, %SEM ≤ 7%). This confirmed the minimisation 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 5).

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 to 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) (Figure 9).

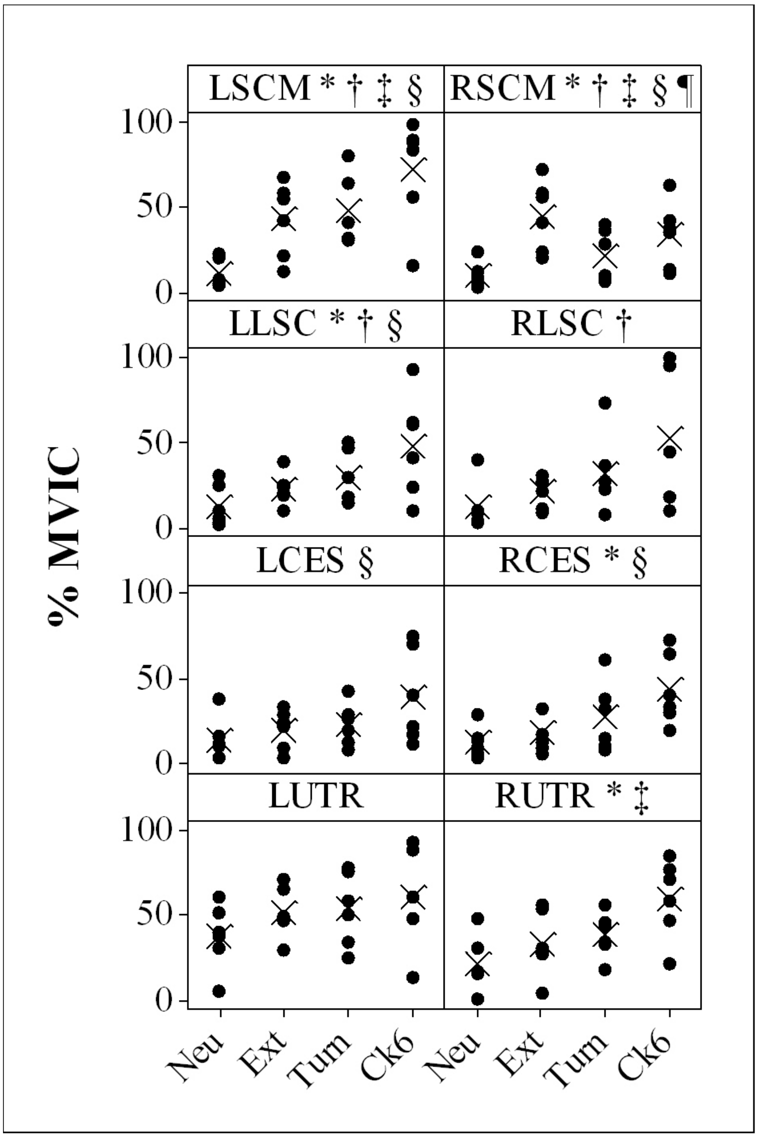

Figure 8. Individual neck muscle activation at +5Gz. X indicates the mean value and dots indicate individual subject data.

* significant difference when Neutral was compared to Check-6 ($P \leq 0.023$)

† significant difference when Neutral was compared to Turn ($P \leq 0.048$)

‡ significant difference when Neutral was compared to Extension ($P \leq 0.006$)

§ significant difference when Extension was compared to Check-6 ($P \leq 0.046$)

¶ significant difference when Turn was compared to Check-6 ($P \leq 0.041$)

Table 5

Within-Subject Repeatability of Head Kinematic Data When Each Head Posture was Repeated Post-Flight

	Axial Rotation		**Extension**		**Lateral Bending**	
	ICC	*%SEM*	*ICC*	*%SEM*	*ICC*	*%SEM*
ROM	0.89	3.8	0.91	2.1	0.91	2.6
Neutral	0.94	1.7	0.88	5.5	0.89	2.8
Extension	0.88	5.8	0.93	3.6	0.90	2.6
Turn	0.95	2.4	0.88	4.4	0.94	2.2
Check-6	0.83	6.5	0.92	2.4	0.85	6.9

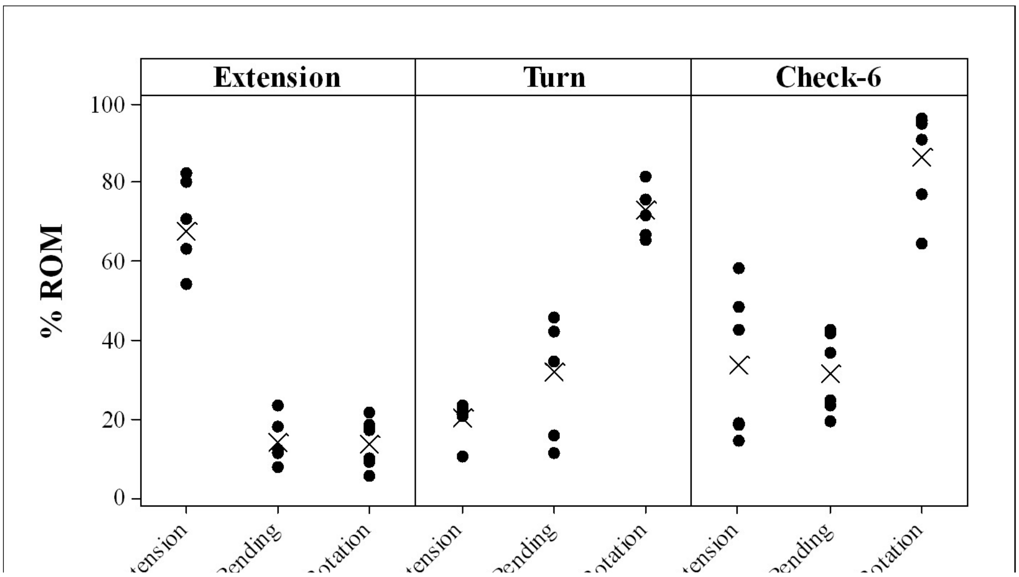

Figure 9. Head position relative to range of motion (%ROM) in the three non-neutral ACM-related head postures. X indicated the mean value and dots indicate individual subject data.

Discussion

Reports of neck injury in HPCP are commonplace in the aviation medicine literature and these injuries have been suggested to be caused by the repetitive exposure to combinations of hyper-gravity 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 hypothesised 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 hyper-gravity in HPCP (12, 13, 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 scrutinised (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 to other studies. Interestingly, levels of muscle activation at +5Gz recorded in this study were similar to those recorded in studies simulating low-velocity rear impact collisions (19).

At +5Gz, 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 towards 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 minimise shoulder musculature contributions towards head and neck stabilisations. Further, greater activation levels were noted in LSCM when compared to 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 to be increased.

Due to constraints with aircraft hardware and avionics, hardware synchronisation 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 analysed with time synchronisation. Consequently, HPCP would probably be anticipating sudden +Gz onset with ACM, therefore the mechanism of neck injury similar to that of whiplash associated disorders should be discounted (28). The need for stabilisation 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 +5Gz and the Check-6 head posture (Figure 8). Musculoskeletal modelling 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 near 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 to 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-month 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 from 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.

Conclusions

It is clear that neck injury in HPCP is a unique occupational hazard. Head stabilisation 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 modelling studies and studies examining efficacious strengthening of the neck and shoulder muscles is suggested.

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CHAPTER 4

VALIDATION OF A SUBJECT-SPECIFIC EMG-DRIVEN, GRAPHICALLY-BASED ISOMETRIC MUSCULOSKELETAL MODEL OF THE CERVICAL SPINE

Abstract

EMG-driven musculoskeletal modelling is a method in which loads on the passive structures of the cervical spine may be investigated. Examination of neck loads in occupational tasks such as those typically experienced by high performance combat pilots may be of importance. A commercially available model of the cervical spine (32) exists however, it has yet to be validated against a gold standard measure. Further, neck muscle morphometry in this model was derived from elderly cadavers and deep neck muscles are driven by surface electrodes which both may threaten model validity. Therefore, the overall aim of this study was to examine the validity of a graphically based EMG-driven musculoskeletal model of the cervical spine. Five healthy male subjects participated in this study which consisted of three parts. Subject-specific neck muscle morphometry data was obtained using magnetic resonance imaging (MRI) as well as EMG drive being generated from both surface (Drive 1) and surface and deep muscles (Drive 2). Finally, to validate the model, net moments predicted by the model were compared against net moments measured by an isokinetic dynamometer in both maximal and sub-maximal isometric contractions with the head in neutral and non-neutral head postures. Neck muscle physiological cross-sectional areas were greater in this study when compared to previously reported data. Further, a linear EMG-Torque relationship was found in the agonistic neck muscle groups examined. It was concluded that the graphically-based EMG-driven musculoskeletal model of the cervical spine examined in this study was insufficiently valid to examine the hypotheses outlined in this thesis. A number of factors could potentially improve the model's validity with the most promising of these being optimising the various modelling parameters using methods established by previous researchers investigating other joints of the body.

Introduction

Neck pain is common in relatively static occupational situations such as dental work, nursing, sitting in front of video display units, sewing machine operating and computer aided designing (23, 27, 29) and in dynamic situations such as automobile accidents (2, 30). Investigating mechanical loading patterns and the distribution of these loads between the active (muscle and tendon) and passive (ligament, bone and intervertebral disc) systems of the body (24) in tasks such as those mentioned above, is of importance when attempting to determine the mechanisms of cervical spine injury. However, the estimation of cervical spine loading *in-vivo* is difficult due to the inaccessibility of its component structures therefore, musculoskeletal modelling has been considered an appealing method of investigation.

In comparison to other joints of the body, the cervical spine has proved complex to model. Therefore, simplifications to cervical spine musculoskeletal models have included; firstly, representing the cervical spine as either a single (6, 21) or a two-joint system (28) secondly, predicting maximal force generating capacity of muscle through estimates of cervical muscle morphology from anatomical texts (6, 21) and elderly cadavers (32) and finally, estimating deep muscle activation patterns from those obtained from superficial cervical muscles (6). These simplifications however, may threaten the validity of such models.

The common problem in musculoskeletal models of indeterminacy, where there are an infinite number of solutions to achieve equilibrium when modelling a certain body joints, is typically addressed by optimising the activation patterns from several muscles (5, 6, 21, 28). However, this approach has been criticised as muscle forces are minimised to create a state of equilibrium, which in turn, minimises the magnitude of antagonistic co-contraction (6). Consequently, techniques for incorporating muscle activation measured by EMG as input into musculoskeletal models has been utilised to overcome this problem (6, 7, 20). Therefore, certain musculoskeletal models are thus considered as “EMG-driven”. A majority of EMG-driven musculoskeletal models utilise a three-component mathematical representation of muscle (3, 10, 33) and details of muscle morphometry allow generic muscle force-length and force-velocity curves to be scaled (3, 33). Further, if the EMG-Force relationships of the muscles being modelled are seen to be non-linear, mathematical manipulation of the EMG signals are needed to enhance model fidelity (3).

An anatomically detailed EMG-driven musculoskeletal model of the cervical spine is available as a commercial software package (8, 32). In an attempt to make the model anatomically accurate, Vasavada et al. (32) utilised data such as the physiological cross sectional area (PCSA) of the neck muscles, optimal fascicle length and pennation angle from the detailed cadaver study of Kamibayashi and Richmond (14). Obtaining PCSA data from elderly cadavers (14) for use in a musculoskeletal model depicting the normal population may be criticised as these data are not representative of healthy young adults. Further, the model has been shown to be highly sensitive to variations in muscle PCSA (1 SD change in PCSA caused a 25-32% change in neck moments generated) (32). Consequently, a so-called "hybrid approach" of combining data from cadaver studies with magnetic resonance imaging (MRI) data from living subjects (9) has been previously used in a combined finite element and musculoskeletal model of the cervical spine (5, 31). Specifically, Van Ee and associates (31) combined optimal fascicle length data obtained from cadavers with muscle volume estimates obtained from MRI of 50th percentile males to calculate neck muscle PCSA. Whilst such an approach has certainly improved the anatomical representation of the cervical musculature, muscle CSA (necessary for calculating the PCSA) was not corrected for orientation of the muscle with respect to the MRI scan. This factor has been considered in a previous study pertaining to the lumbar spine (19).

Intramuscular EMG is a technique that has been used to study the deep musculature of the cervical spine (4, 16). A previous study conducted by McGill and associates (18) examined whether activation of deep muscles could be represented by activation of the surface musculature in the lumbar spine. From this study it was concluded that this was an acceptable approach as the errors in the signals were limited to 10-15% of maximum voluntary contraction. The approach undertaken by McGill and co-workers may be useful for estimating deep muscle activation from surface electrodes with application to cervical spine models.

The utility of most musculoskeletal models is dependant upon their ability to accurately predict natural, biological phenomenon (10). Due to ethical constraints, direct measurement of muscle force *in-vivo* is impossible therefore, a number of different methods have been utilised to validate the model's output. Generally, an external summation of torque about the axis of rotation for the modelled joint is measured synchronously (3, 33) and this is then used as a "gold standard" for comparison to a model's predictions. This approach has yet to be utilised in cervical

spine models. Further, the opportunity to validate subject-specific models is a recent development of interest by other researchers (1).

Therefore, the overall aim of this study was to validate the graphically based EMG-driven musculoskeletal model of the cervical spine created by Vasavada et al. (32). This was done using subject-specific neck muscle morphometry data obtained from MRI in addition to the pre-existing muscle architecture data used by the model. Further, the model's cervical musculature was driven using both surface and deep EMG. To validate the model, net moments predicted by the model where compared to net moments measured by an isokinetic dynamometer in both maximal and sub-maximal isometric contractions with the head in neutral and non-neutral head postures.

Methods

Subjects

Five healthy male subjects (mean (SD) age: 31.4 ± 9.1 yrs, height: 1.77 ± 0.07m, weight: 78 ± 4.8kg) participated in the study. Ethical approval for the study was obtained from the Institutional Human Research Ethics Committee. Exclusion criteria as outlined by Sommerich et al. (29) for neck EMG measurement was adopted and informed consent obtained was from each subject prior to the commencement of testing.

Experimental Protocol

This study was divided into three parts. The first part of the study consisted of the generation of subject-specific muscle morphometry data derived via MRI. The second part involved the synchronised collection of surface EMG data, intramuscular EMG data in addition to torque data from an isokinetic dynamometer. Neck torque data was collected for two reasons; firstly, to examine the EMG-Torque relationship (as being representative a EMG-Force relationship) in cervical muscle to determine whether this relationship was linear (which would then be needed for the musculoskeletal model) and secondly, to later compare the net torque estimates generated by the Vasavada et al. (32) model for the purpose of model validation. The third part describes how changes to the Vasavada and associates (32) model were implemented, and the subsequent comparison of the predicted and measured net torque data was then conducted. Validation of the model was undertaken in a series of head postures with maximal

(100%) and sub-maximal (15% and 60%) isometric contractions. The data collection and analysis methods related to each part of the study are outlined in turn below.

Part 1 – Generation of Subject-Specific Neck Morphometry Data

Morphometry of the neck muscles was determined from MRI scanning of the cervical spine. A Siemens 1.5T Sonata scanner was set at a spin-echo sequence of TR = 720ms and TE = 240ms, and generated slices 6mm in thickness. Combined spine and neck array coils were used. A total of thirty slices were taken ensuring that structures surrounding the seven cervical vertebrae, as well as the first four thoracic vertebrae were imaged. The scanning protocol was designed so that these slices were taken as close to parallel to the top of the vertebral body where possible. However, this could not be done in all cases as it was impossible to correct for the natural lordosis of the cervical spine. In addition to these transverse scans, a mid-sagittal scout view which had the slices associated with the MRI scan superimposed on it, was also obtained for each subject to allow for correction of the scan angle to the vertebrae (Figure 10). All images were stored in DICOM format for later analysis. All scanning was performed by the Senior Radiographer at the Sir Charles Gardiner Hospital MRI unit in Western Australia.

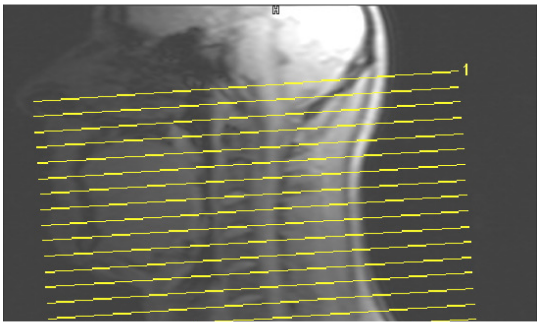

Figure 10. Mid-sagittal scout view with superimposed scan lines.

Data Analysis

The analysis procedures related to the use of MRI-derived muscle morphometry were divided into three steps. These steps were; firstly, all scans were digitised, secondly, the resulting CSA's were corrected for scan angle and muscle orientation and lastly, muscle CSA was converted to muscle PCSA to determine the force generating capacity for each muscle.

MRI slices representing each of the cervical and thoracic vertebral levels (C1-T4) were chosen for analysis. These scans were then analysed using Scion Image software (Scion Corporation, USA) and an IBM computer. Images were imported into the software program then the greyscale values (0-255) were inverted, and the image was sharpened using a filter available in the software. A calibration factor for each scan was contained within the file, so no further calibration of the image was required. To assist in digitising each image, a large flat screen monitor (610mm) with high resolution (1920x1200) was used. Muscles were outlined using the freehand cutting tool that was manipulated using the PC's optical mouse.

Through an extensive pilot study it was decided that the following muscles would be analysed. These muscles included; sternocleidomastoid (SCM), levator scapulae (LS), semispinalis capitis (Semi Cap), semispinalis cervicus (Semi Cerv), splenius capitis (Spl Cap), longissimus capitis (Log Cap) and obliqus capitis inferior (Obl Cap Inf). The appearance of these muscles as seen in MRI scans is shown in Figures 11a-11g. The criterion for muscles to be included in this part of the study was that they had to be clearly distinguishable and traceable in the MRI scans. Identification of the muscles examined in the part of the study was confirmed via a CD-ROM of the neck anatomy taken from MRI scans (Interactive Spine, Primal Pictures Ltd) and a radiographic atlas displaying transverse slices similar to those taken in the MRI scanning.

Other cervical muscles such as the scalenes group, longus capitis and colli, loggissimus cervicus, iliocostalis cervicus, splenius cervicus, trapezius, rectus capitis posterior and oblicus capitis superior could not be easily digitised as they were either inter-twined with other cervical muscles or they could not be separated within a larger muscle group. Therefore, their fascial boundaries were not clear and hence their measurement could not be considered as valid or reliable. Following the outlining of the analysed muscle's fascial boundaries, raw CSA of all muscles were collated for each

subject at each vertebral level. As it was impossible to have all scans taken perpendicular to the analysed muscles lines of action, some perspective error would have been present in the raw CSA if not corrected (19). Therefore, in this study a similar approach to that used by McGill and associated was utilised with raw CSA data being corrected for muscle line of action in addition to scan angle. Corrections due to scan angle were derived from the MRI scout view, whilst corrections for muscle orientation were calculated from the Vasavada and associates (32) cervical spine model where each muscle's origin and insertion was detailed. The method in which correction for scan angle was performed is outlined below.

A right hand coordinate system was formed as follows X (+ve forwards), Y (+ve upwards) and Z (+ve right). It was assumed the MRI slices were taken with no angulation from either the x- or y-axes therefore, to adjust the scan plane to a vertebral coordinate system a rotation about the z-axis was required. For each subject, the magnitude of rotation for each slice was obtained by measuring this angle (θ_1) from the top of the C4 disc using Aros Magic Viewer Software (Aros Magic, USA). To correct for muscle line of pull two angles were required. A rotation about the x-axis (φ) was necessary followed by a second rotation (in addition to that of the scan angle) about the z-axis (θ_2). These latter two angles were derived from the muscle origin and insertion data from the Vasavada and associates model. In the data files for the model each muscle's origin and insertion was given specific to the bone which it joined hence to transform these coordinates into a global coordinate system with its origin in the 12th thoracic vertebrae, the X, Y and Z coordinates were adjusted. However, for muscles inserting into the scapula these coordinates had to be transformed using a rotation about Y (ϕ) then X (φ) followed by a translation. The rotation matrix used to transform the scapula coordinates was as follows:

$R_{YX} =$

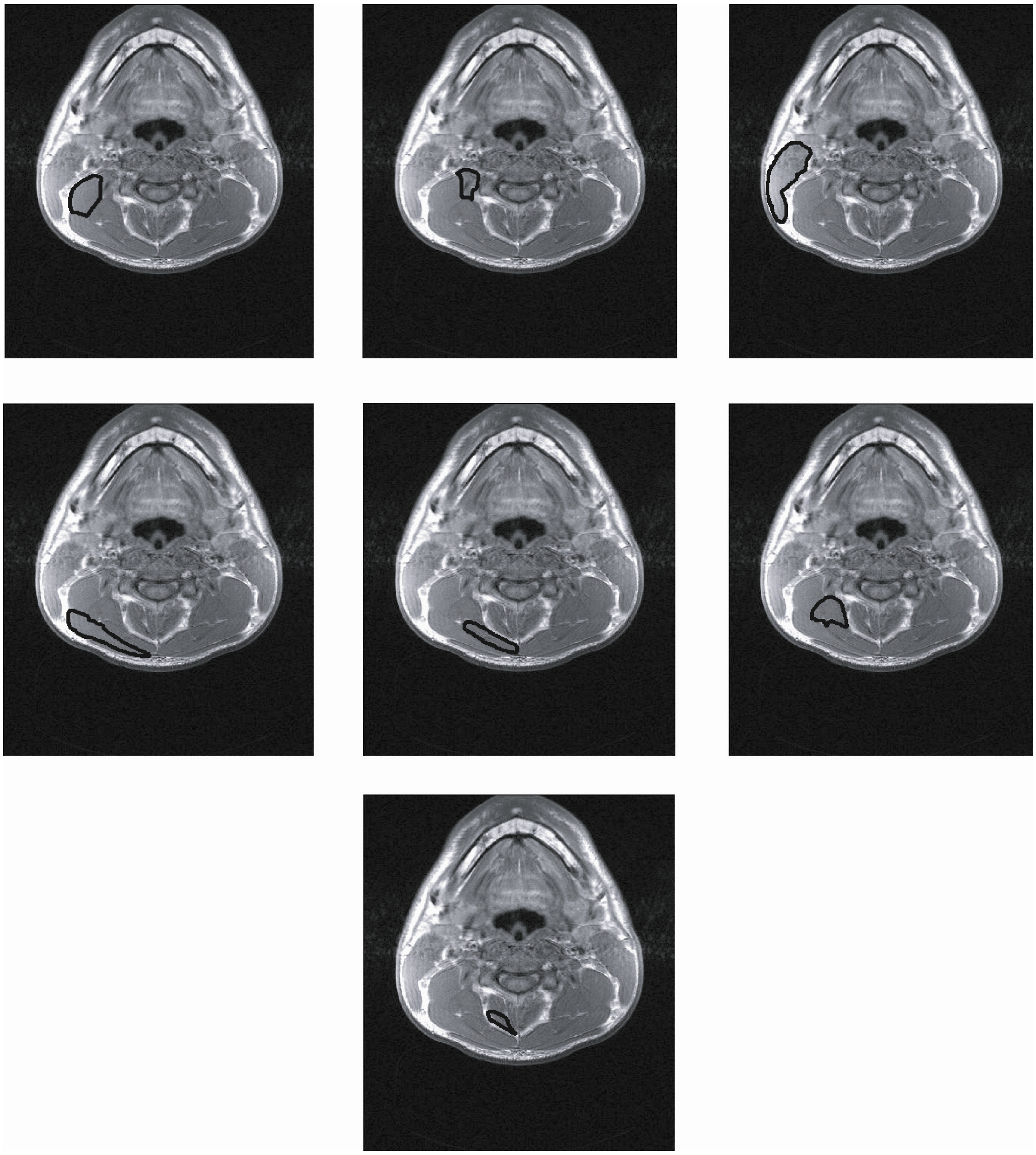

Figure 11a-11g. MRI images at C3 level with analysed muscles outlined. Muscles are denoted in this order reading from the top left-hand corner picture across: levator scapulae (LS), longissimus capitis (Log Cap), sternocleidomastoid (SCM), splenius capitis (Spl Cap), semispinalis cervicus (Semi Cerv), semispinalis capitis (Semi Cap) and obliqus capitis inferior (Obl Cap Inf).

Consequently, for this study the corrected CSA (CSA_C) can be calculated from the raw digitised CSA (CSA_R) via :-

$$CSA_C = CSA_R / (\cos(\theta_1 + \theta_2) * \cos\varphi)$$

Once the corrected muscle CSA values were determined for the selected muscles at each vertebral level PCSA was calculated. Typically, PCSA is calculated by dividing muscle volume by the muscle's optimal fibre length (14). The optimal fibre lengths for each muscle were obtained from Kamibayashi and Richmond (14). Muscle volumes, determined from the scans were obtained by multiplying the CSA at each vertebral level by the respective vertebral height, which was obtained from the digitised MRI scout view. The vertebral height was defined as the height of a vertebrae plus the height of the inferior intervertebral disc. The scout view image was calibrated using the known scan interval value of 6mm.

Part 2 – Surface and Intramuscular EMG of Neck Muscles and Neck Muscle Dynamometry

As mentioned in the Introduction section, a graphically-based musculoskeletal model of the cervical spine has previously been created (32). The muscles in this model can be driven by neck muscle activations to compute a net joint moment. To date, the model has yet to be validated against a measured criterion in a subject-specific manner. Thus, to contribute to the validation process, surface and intramuscular EMG data from selected neck muscles was collected from the subjects that participated in the abovementioned MRI study.

Subjects performed a total of 18 maximal (100%) and 36 sub-maximal (15% and 60%) isometric contractions against a semi-rigid flat pad attached to the torque arm of an isokinetic dynamometer (Cybex 6000, Ronkonkoma, NY). Three different head-neck postures were tested in both flexion and extension directions. These postures included a self-regulated neutral posture, 20° of flexion from the neutral posture, and 35° of extension from the neutral posture. Whilst the position of the head for Cybex testing was itself defined by the measurement apparatus related to the Cybex, the neutral head

posture needed to be defined relative to a global reference so that these postures could be transformed relative to the neutral posture defined by the model. Therefore, two-dimensional kinematics data were obtained from an orthogonally placed video camera (Panasonic NV-GS 180, Matsushita Group, Japan) mounted on a tripod. The transformation procedures are detailed in Part 3 of the methods section.

As the number of contractions was high, only isometric contractions in the flexion and extension directions were tested and used for validation. The outline of the experimental protocol is shown in Table 6. Tests in each posture and contraction direction consisted of three, five-second MVICs followed by two, five-second 15%-MVICs and two five-second 60% MVICs. Whilst performing these contractions synchronised EMG and torque data were collected. Data were only recorded from the last two contractions for the maximal condition (22, 29). Contraction directions and testing methods were randomised to avoid any ordering effect and a two-minute rest period was required after each exertion to allow full recovery.

Table 6

Outline of the Experimental Protocol Used

Contraction Direction	Head Position	Intensity (Surface EMG)	Intensity (Surface and Intramuscular EMG)
Flexion	Neutral	100% MVIC	100% MVIC
	20° Flexion	60% MVIC	60% MVIC
	35° Extension	15% MVIC	
Extension	Neutral	100% MVIC	100% MVIC
	20° Flexion	60% MVIC	60% MVIC
	35° Extension	15% MVIC	

Data Collection

During testing subjects were seated in a fabricated armless chair that utilised a five-point racing-car harness system so that the neck was isolated. The semi-rigid flat pad of the dynamometer was moulded slightly to the subject's head allowing resistance to be provided orthogonal to the intended movement in an effort to minimise extraneous non-planar movements. Subjects were positioned so that the axis of rotation of the torque arm was aligned to each subject's C7 level for each exertion. The centre of pressure for contractions in extension was the mid-point of the external occipital protuberance whilst for flexion it was the main protuberance of the forehead. This method of data collection has previously been found to be highly reliable in producing sub-MVIC and MVIC for surface (22) and intramuscular (4) EMG in the neck muscles.

Torque histories from all contractions were recorded from the dynamometer with averaged peak torque values from the two MVICs being used as the basis for determining the level of torque for 15% and 60%-MVIC trials. During these trials, subjects were given real-time torque history visual biofeedback using a second LCD monitor. To allow for more precise sub-maximal efforts, a line depicting the required sub-maximal torque level (based on maximal efforts) was superimposed on the torque-time graph. Concise verbal instructions were also given to each subject to increase force until the pre-determined sub-maximal torque value was reached and then subjects were asked to maintain this torque value. Furthermore, verbal encouragement was given for maximal trials.

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 summarised below:

- Left and Right Sternocleidomastoid (SCM) - 1/3 distance from the sternal notch to mastoid process, over the main muscle belly (11, 22);
- Left and Right Levator Scapulae (LS) - Midway between the posterior border of sternocleidomastoid and the anterior border of upper trapezius (22);
- Left and Right Cervical Erector Spinae (CES) – 1cm from the spinous process at the C4/5 level in a bipolar configuration and placed between the anterior border of trapezius, in line with muscle fibres (22);

- Left and Right Upper Trapezius (UTR) – Lateral to the midpoint between C7 and the posterior acromion shelf, along the line of upper trapezius muscle fibres (12).

Excess body hair was removed and the area was abraded then cleaned with an alcohol swab. Pairs of 12mm diameter Ag-AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN, USA) were adhered to the skin 20mm centre-to-centre distance apart (22) along the muscle fibre orientation. An impedance meter was then used to ensure an impedance reading of <10kΩ prior to collection. In order to synchronise EMG with torque, a raw voltage signal depicting torque was captured from the dynamometer via BNC connectors. Both EMG and torque data were sampled at 1000Hz using a 16 channel Grass Amplifier Rack (Astro-Med Inc, West Warwick, RI) containing a differential amplifier rack (input impedance: 20MΩ, SNR: 18dB, CMRR: >40dB at 60Hz) and a variable, fixed gain (range: 1000-10,000) was used. The Grass system was interfaced with a computer running a customised software program using LabVIEW V7.1 (National Instruments, Texas, USA) utilising a 16 bit A/D board (PCIMIO16XE50, National Instruments, Texas, USA) to captured all the data and provide onscreen histories for instantaneous biofeedback. Only signals from the last 2 contractions were used for analysis.

Since surface EMG was to be used as input to the model, a clearer understanding of the activation patterns in the deep musculature was needed. Therefore, intramuscular EMG examination of the neck muscles in neck extension at 60% and 100% was conducted on three of the five subjects. Intramuscular EMG was measured unilaterally from the right Semi Cap and Spl Cap with corresponding surface EMG recorded from right LS and CES locations. Intramuscular EMG recordings were made using bipolar fine-wire electrodes insulated with Teflon (50.8μm, Nicolet Healthcare, Madison, RI). The end of the wire was stripped (the first wire was stripped 2mm, while the second wire was insulated 3mm from the end then stripped 2mm) which allowed isolated recording of EMG from the target muscle only. A small hook at the end of the fine-wire kept it in a stable position once inserted. Each subject's skin was sterilised and local anaesthetic (1% lignocaine) was injected subcutaneously. All intramuscular fine wire insertions were performed by a medically trained neurophysiologist.

Prior to intramuscular electrode insertion, the fine-wire electrodes were preloaded into a twenty-five gauge hypodermic needle to enable insertion. Accurate anatomical localisation was achieved using ultrasound (Model SSA-220A - CAPASEE II, Toshiba Medical System, Japan) to visualise the local soft tissues. A 7.5MHz probe (PVG-720S) was used to optimise superficial soft-tissue resolution. For Semi Cap, the needle was inserted 2.0-3.0cm lateral to the midline, in the posterior-anterior direction. Under ultrasound guidance, the needle was then advanced to within the fascial boundaries of the muscle, then withdrawn leaving the hook wires in place. For Spl Cap, the needle was inserted 2.5-3.5cm lateral from the midline, aiming anteromedially and using ultrasound guidance as described above. If there was ultrasonographic evidence that the wires had migrated at the end of the test protocol then the trial was considered void. Using this method of exclusion, no trials were considered void in this study.

The fine-wire electrodes were taped to the skin at the puncture site. The non-insulated tips were attached to micro-grabbers (Nicolet Healthcare, Madison, RI) and the 1.25m lead was finished with a DIN-42-402 connector allowing direct compatibility to the electrode board. The micro-grabbers were also taped to the skin to inhibit the potential displacement of the fine-wires. Following intramuscular electrode insertion the subject's skin was thoroughly prepared in a similar fashion previously described and surface electrodes in the right LS and CES locations were affixed.

Data Analysis

Torque and EMG signals were exported as ASCII text files to a customised LabVIEW V7.1 (National Instruments Inc., Texas, USA) program where raw EMG data were demeaned, high-pass filtered at 15Hz to remove any movement artefact, full wave rectified and low pass filtered at 4Hz to produce a linear envelope. A fourth-order, dual pass Butterworth digital filter was used for all filtering. MVIC values were obtained from the average of the last two of the three maximal contractions (4, 29) and a 200-msec moving window was applied to the linear envelope to extract this value. Raw torque signals from the dynamometer were collected at 1000Hz when typically it is measured at a lower sampling rate (e.g. 50-200Hz). As such, noise due to over-sampling had to be removed and data was therefore low pass filtered at 4Hz using the abovementioned filter. A maximum value from this smoothed signal was obtained and used to derive an EMG-Torque relationship. This relationship was important for model

development as it would indicate the need for further EMG processing to account for any non-linearity (3).

Prior to data collection, the dynamometer was calibrated using Cybex calibration weights placed on torque arm of the dynamometer at 90 degrees. Torque data from the dynamometer was matched to a voltage measured on the Grass Amplifier. Five increments were used after which a linear regression was computed for voltage and torque where 1V = 72.945 Nm with a $R^2 = 0.9998$. This value was used for converting future voltage measurements to torque.

Part 3 – Variations to, and Validation of the Vasavada et al. Model

A subject-specific model for each subject in the study was created based on the standard Vasavada et al (32) model using Software for Interactive Musculoskeletal Modeling (SIMM – Musculographics Inc). Each of these models included subject-specific muscle morphometry data derived from Part 1 of the study as well as EMG drive from Part 2. The validity of the model was assessed by comparing the predicted torque from the model against the measured neck torque from dynamometry.

Experimental Protocol

In the cervical spine model, seven of the 19 muscles modelled were analysed using MRI as described in Part 1 of the study. All of these seven muscles with the exception of SCM were represented as single equivalents allowing convenient conversion from muscle PCSA to maximum force generating capacity through multiplication via the PCSA to Force constant of $35N/cm^2$ (32, 33). However, the model represented the SCM as three sub-volumes with three distinct origin and insertions with differing force generating capacity. As these sub-volumes of SCM could not be distinctly outlined to determine their PCSA, a method to calculate the force generating capacity of each of the sub-volumes was required. Accordingly, the muscle origin and insertion data in addition to the force generating capacity from the model in combination with the SCM PCSA from MRI analysis was used to calculate unit vectors (UV) and force vectors (FV) for each sub-volume by:-

$$FV = F.\ \frac{u}{|u|}$$

A resultant force vector was then calculated from the sum of the three sub-volume force vectors. The magnitude of the resultant force vector was used to calculate a percentage contribution from each sub-volume. This percentage was then used to apportion the total force generating capacity to each sub-volume. The remaining 12 muscles not analysed using MRI were altered (increased) by the average percentage difference of the seven muscles analysed compared to the same seven muscle measured from cadaveric data reported in the literature (14). These differences in PCSA were calculated for each individual subject in this study.

All neck muscles in the neck model were represented as graphical lines. When the head was place in extreme postures near end of range, a number of muscles (lines) had a tendency to overlap each other as well as merge into certain bony prominences. Therefore, wrapping objects were placed over intersecting muscle lines as well as over affected bony prominences at these specific postures to prevent such physiological inconsistencies. The alterations to the model were performed using the software's interface tools (SIMM, Musculographics).

As previously described, each subject adopted a self-regulated neutral head posture during data collection in the dynamometer. To transform this posture to that presented in the model, a mid-sagittal digital picture of each subject's neutral posture was captured from the digital video recording using Adobe Photoshop v7 (Adobe Systems Incorporated, San Jose, CA). A line connecting the outer cantus and the external auditory meatus was drawn on the picture using the software. The angle from the vertical was then calculated and recorded. The model was then place in a mid-sagittal view and a picture from this view was taken using the functionality of the model's software. This picture was imported into Adobe and a similar line was drawn, then the angle was calculated. The difference in the two angles allowed a correction factor in flexion or extension to be determined for each subject and this was applied to each model. For each subject, a second image of the model with the change in neutral head position was taken in SIMM. This picture was superimposed over the picture of the subject to ensure the accuracy of the correction.

Finally, the level of muscle activation for each muscle modelled was used as input to the model by two methods. Firstly, since it was impossible to capture EMG from all 19 muscles using surface measuring techniques, deep muscles were driven by surface measured signals. Secondly, in an attempt to increase the validity of the model, differences between surface and intramuscular EMG data were then incorporated into a second round of validation. Table 7 summarises both these approaches. Moreover, for input into the model the level of activation was required to be between 0 and 1, with 1 depicting a fully activated muscle. A maximum value of activation from the normalised EMG histories obtained from Part 2 of this study was correspondingly scaled on a level of 0 to 1. This maximum value was obtained from the plateau portion of the isometric contraction and a corresponding maximal torque value recorded from the dynamometer was obtained for comparison. Maximum activation values were obtained for all electrode placements and these values, along with the static head posture, were used to create motion files that were used as input to the model. These procedures were performed at a source code level. Code for the model is protected by copyright and thus has not been published in this thesis. However, for the interested reader Delp and Loan (8) provide a technical overview of the software.

Data Analysis

Following the input of all subject-specific data, the model was used to calculate a net isometric torque. These were calculated from both maximal and sub-maximal conditions as well as neutral and non-neutral postures. Neck torques predicted by the model was compared to the corresponding measured torque output from the dynamometer.

Statistics

Descriptive statistics were used to analyse the difference in PCSA values previously reported in the literature compared to our MRI derived values. Processed maximal and sub-maximal EMG values were graphed against the corresponding torque value with the results from the (R^2) linear regressions calculated for all contraction directions and head postures to establish the linearity of the EMG-Torque relationship in the cervical spine musculature.

Table 7

Neck Muscle Drive Used in Validation

Muscle Group and Muscles in the Neck Model	EMG Drive 1	EMG Drive 2
Flexors: Sternocleidomastoid, Scalenus Anterior, Longus Capitis, Longus Colli	Surface SCM	Surface SCM
Lateral Flexors: Scalenus Medius, Scalenus Posterior, Levator Scapulae, Loggissimus Capitis, Loggissimus Cervicus, Iliocostalis Cervicus, Splenius Capitis, Splenius Cervicus	Surface LS	Surface LS / Intramuscular
Extensors: Semispinalis Capitis, Semispinalis Cervicus, Trapezius (Clavo), Rectus Capitis Posterior Major, Rectus Capitis Posterior Minor, Oblicus Capitis Superior, Oblicus Capitis Inferior	Surface CES	Surface CES/ Intramuscular
Trapezius (Acromio)	Surface UTR	Surface UTR

The percentage coefficient of variation (%CV) was calculated between the measured torque signals from the dynamometer and the predicted values from the model. This method assesses variation between predicted and measured torque for contraction-direction/head-position at a time. The %CV is calculated as follows: -

Where, d^2 is the squared difference between the neck torques measured from the dynamometer and neck the torques predicted by the model and x_{pair} is the mean of these two measurements (15).

Results

Of the seven muscles analysed in this study, SCM recorded the largest average PSCA value (5.54 cm^2) whilst and Log Cap was the smallest (1.11 cm^2). Figure 12 provides a summary of all muscles analysed. On average, neck muscle PCSA obtained in this study was 31% greater than previously reported cadaveric data and 15% greater than previously reported hybrid approaches (14, 31). Obl Cap Inf had the largest increase in PCSA compared to cadavers (+152%) and hybrid (+66%) whilst Semi Cerv had the largest decrease compared to cadavers (-52%) and hybrid (-15%). Figure 13 compares PCSA values obtained for the seven muscles analysed in this study to previous reports in the literature.

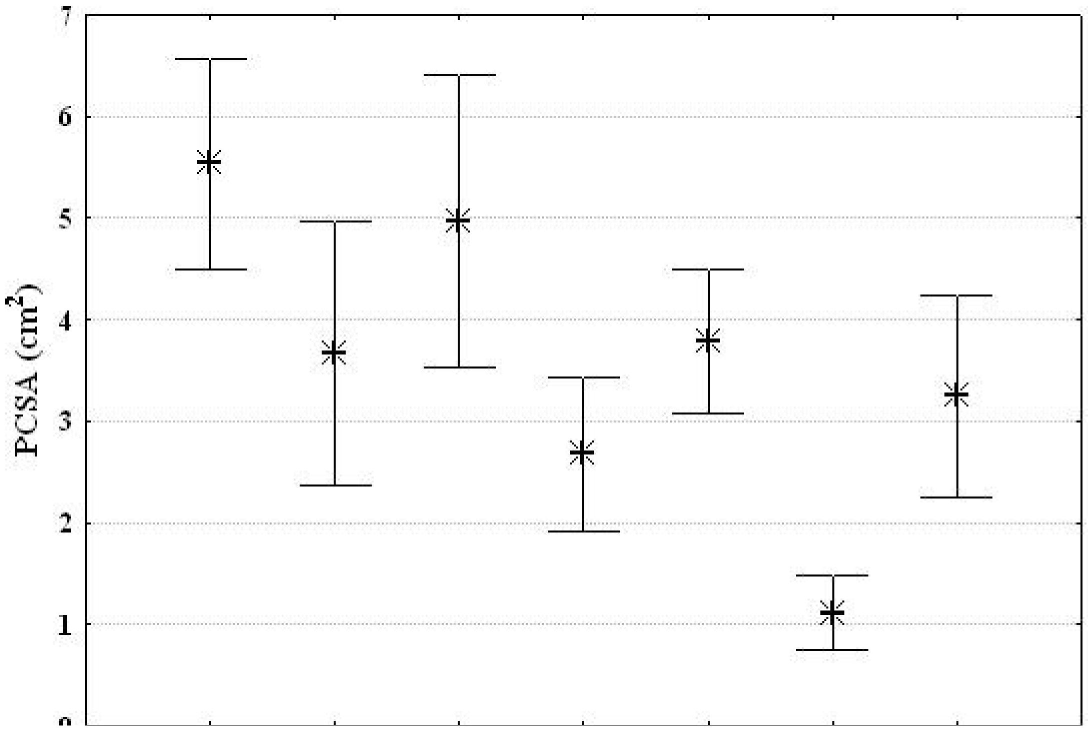

Figure 12. Average PCSA values obtained from MRI. Error bar = 1 standard deviation.

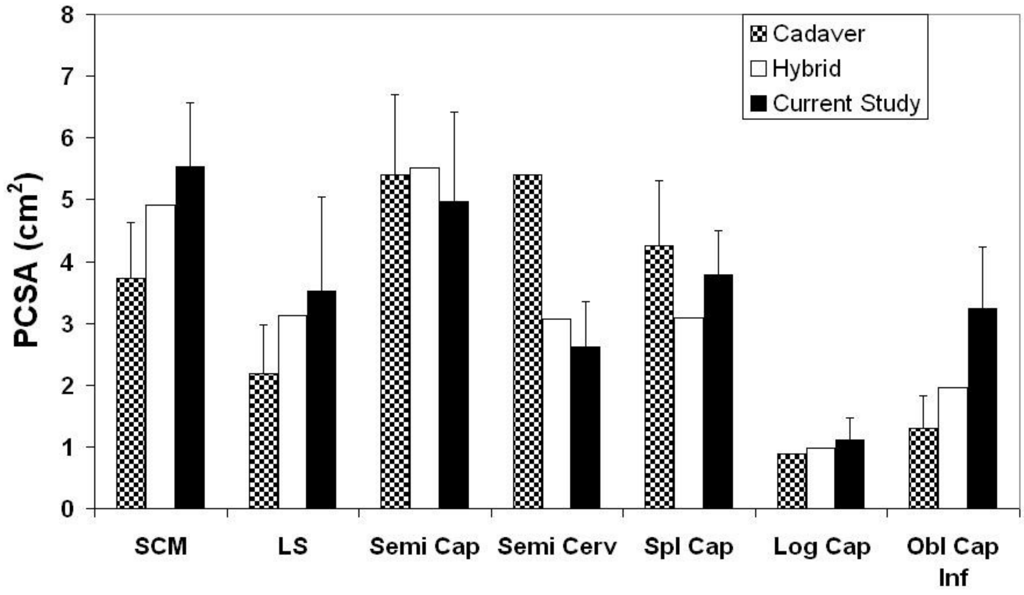

Figure 13. Comparative analysis of previous data to the current study's values of PCSA for the seven muscle analysed. Error bar = 1 SD. Values without error bars indicate no standard deviation calculated or reported. Cadaver data were summarised from Kamabayashi and Richmond (14) and hybrid data were from van Ee et al. (31).

EMG-torque relationships for agonists were approximately linear in all contractions tested (group mean R^2 = 0.95) (Table 8). In comparison, antagonistic muscle groups displayed lower levels of linearity (group mean R^2 = 0.8) with extension in neutral exhibiting the lowest level of linearity (R^2 = 0.75). Synergistic and stabiliser muscle groups also displayed close to linear relationships (group mean R^2 = 0.85) except in extension in neutral and flexion in extension contractions. This data indicated that no non-linear methods of EMG drive were needed to be considered for use in the neck model and as such, no further processing of EMG were necessary.

SIMM generally overpredicted isometric neck torque at the 15% intensity when compared to the gold-standard values measured by dynamometry in flexion and extension contractions. This finding was not replicated at the higher intensities where comparisons of flexion data at 60% resulted in similar values between the model and dynamometer. Furthermore, comparisons varied at this intensity for the extension contractions. Similarly, varied results were also noted when comparisons were made

between the modelled torque and the measured torque at maximal intensity (100%). This was also seen in both the flexion and extension contractions (Figures 14 and 15).

Table 8

Mean and SD R^2 Values for EMG-Torque Relationship

	Agonistic	**Antagonistic**	**Synergistic/Stabiliser**
Extension	*CES*	*SCM*	*LS, UTR*
In Neutral	0.93 (0.02)*	0.75 (0.27)	0.77 (0.22)
In Extension	0.99 (0.01)*	0.78 (0.10)	0.93 (0.09)*
In Flexion	0.98 (0.03)*	0.85 (0.15)*	0.86 (0.09)*
Flexion	*SCM*	*CES*	*LS, UTR*
In Neutral	0.96 (0.04)*	0.76 (0.23)	0.88 (0.06)*
In Extension	0.86 (0.21)*	0.77 (0.30)	0.76 (0.14)
In Flexion	0.96 (0.03)*	0.88 (0.11)*	0.88 (0.1)*

* denotes $R^2 \geq 0.85$

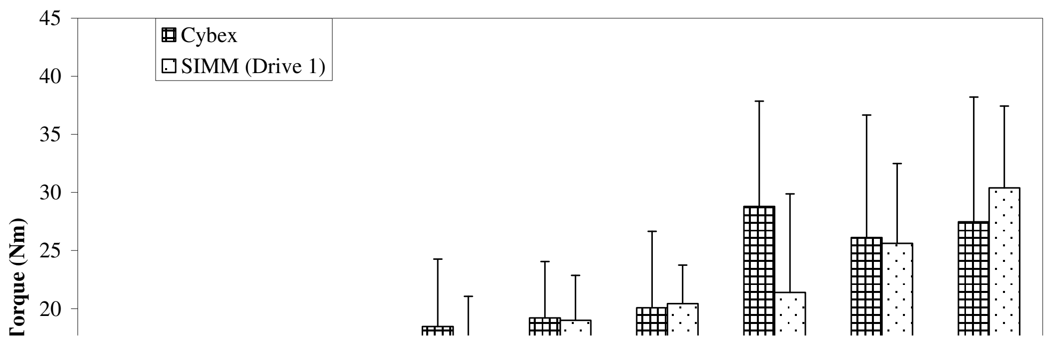

Figure 14. Comparison of flexion neck torques measured by the dynamometer and neck torques predicted by SIMM using surface EMG as drive.

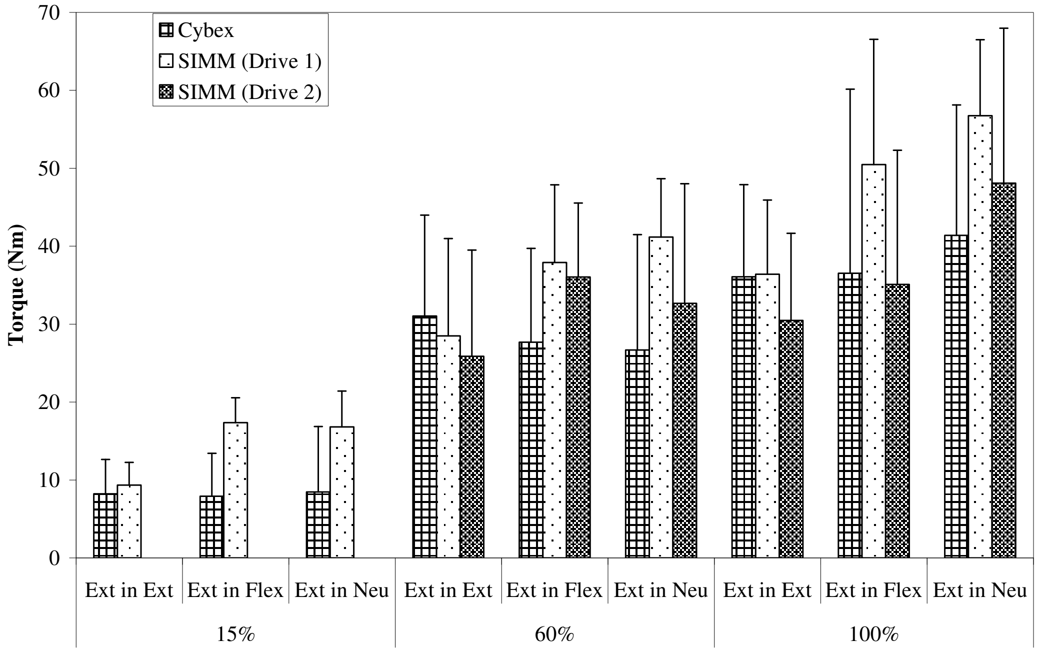

Figure 15. Comparisons of extension neck torques measured by the dynamometer and neck torques predicted by SIMM using surface EMG only (Drive 1) and a combination of surface and indwelling EMG (Drive 2).

There were large variations evident for the relative CV in all contractions and head postures (range = 0.9%-64.9%). For neck extension, the average %CV between neck torque measured from the dynamometer compared to torque predicted by SIMM was slightly better with the inclusion of intramuscular EMG (Drive 2) (20.1%) when compared to driving the model by surface EMG alone (Drive 1) (23.3%). Generally, the predictions were better for neck torque in flexion (mean relative %CV = 18.2%) when compared to extension (mean relative %CV = 28.5%). When surface EMG alone was used to drive the model, only seven of the 18 contractions modelled were deemed to have acceptable validity (%CV < 10%). This number decreased to six with the inclusion of the indwelling EMG signal. Table 9 details %CV in all contractions examined.

Table 9

Summary of %CV Values in All Contractions Modelled

Intensity (MVIC)	Direction	%CV (Drive 1)	%CV (Drive 2)
15%	Ext in Ext	10.7	
	Ext in Flex	64.9	
	Ext in Neu	52.6	
15%	Flex in Ext	6.9*	
	Flex in Flex	62.2	
	Flex in Neu	44.0	
60%	Ext in Ext	7.5*	12.8
	Ext in Flex	27.9	18.6
	Ext in Neu	37.2	14.3
60%	Flex in Ext	10.5	
	Flex in Flex	1.0*	
	Flex in Neu	1.6*	
100%	Ext in Ext	0.9*	11.9
	Ext in Flex	26.8	2.8*
	Ext in Neu	28.3	10.6
100%	Flex in Ext	26.5	
	Flex in Flex	1.7*	
	Flex in Neu	9.0*	
Average	**Flex**	**18.2**	
	Ext	**28.5**	**22.1**
	All Contractions	**23.3**	**20.1**

* denotes acceptable validity (% CV < 10%)

Discussion

The overall aim of this study was to validate a graphically-based EMG-driven musculoskeletal model of the cervical spine. A couple of strategies were employed to facilitate this aim and these included; validating the model to subject-specific neck muscle morphometry data measured by MRI in addition to the including intramuscular EMG to better drive the deep muscles included in the model. Despite these efforts, the results of this study showed an average of 20.1% in the relative CV between neck torque predicted by the model and the "gold standard" neck torque measured by the dynamometer. The following discussion examines the two key inputs used to modify the model, namely muscle morphometry and neck muscle activation and suggests methods to further improve its validity.

The increases in the PCSA data obtained via MRI scans in this study when compared to previously collected cadaveric data was deemed acceptable as measures were of young, healthy men and the cadaveric study measured muscle from a 68-80 years old subject cohort of mixed sex who were reported as have substantial amounts of bed rest before their death (14). Previous research (31) that found smaller differences between a MRI-based hybrid approach and cadavers may be due to the fact that they did not include any correction for the line of pull as performed in the current study. Further, the large increases in PCSA in Obl Cap Inf can be attributed to this correction as this sub-occipital muscle is the least orthogonal to the transverse scan plane (14, 32).

Perhaps the most promising parameter to optimise to improve model validity would be the constant that converts PCSA to maximal muscle force generating capacity. Our model used 35 N/cm^2 as the constant however, values as high as 55 N/cm^2 and as low as 18 N/cm^2 have been reported in the past (3, 9, 31). In an EMG-driven model of the lumbar spine, Granata and Marras (13) suggested including a gain factor to optimise model torque prediction. The inclusion of such a gain factor would definitely increase the validity of our model as the level of error of our model is well within the range of the PCSA to force conversion constant reported in the literature. However, additional questions arise over the exact gain value to use and whether to apply this universally or in a subject-specific manner.

Findings from this study suggest that an approximately linear relationship exists between neck flexion torque and EMG from the neck flexors. A similar finding was also noted in the neck extensors when extension contractions were performed. These

findings are in agreement with previous studies (16, 25). However, a non-linear relationship between the neck extensors and neck extension moments have also been reported by others (26). Buchanan and co-workers (3) suggest processing EMG for non-linearity if signals were being used as input into a musculoskeletal model. In this study, no extra processing of EMG data was considered as the EMG-Torque relationship was considered as close to linear in most instances. This method could however be applied to the signals obtained from the antagonistic muscle of the neck, enhancing the model's validity.

From the results of this study, it was considered that the graphically based, EMG-driven musculoskeletal model of the cervical spine presented by Vasavada et al (32) was not sufficiently valid when compared to a "gold-standard" measurement of torque from a dynamometer even after the inclusion of MRI data, EMG signals and model development. To further improve the validity of this neck model, the parameter adjustment methods based on a non-linear least-square fit optimisation approach as outlined by Lloyd and Buchanan (17) may be useful. In this method, model parameters such as muscle PCSA, model dimensions and force-length characteristics are altered to improve the match between the model prediction and the gold standard. However, the level of complexity of this approach is high as it requires a substantial investment in software development time and also requires far more isometric contractions to optimise curve fitting than that collected in this study (17)

Conclusions

Larger PCSA values of the neck musculature were obtained in this study compared to previously reported values. Further, in this study, a linear EMG-Torque relationship in the agonistic neck muscle groups studied was obtained. Lastly, when validity of a graphically based, EMG-driven musculoskeletal model of the cervical spine was tested against measures from a dynamometer, the best results was 20% CV, despite the inclusion of subject-specific anthropometric, surface and intramuscular muscle activation data.

The findings from this study suggest that the graphically-based EMG-driven musculoskeletal model of the cervical spine is currently not sufficiently valid to examine the hypotheses examined in this thesis. A number of factors could be

considered to improve the model's validity with the most promising of these is probably optimising the various modelling parameters using methods established by previous researchers investigating other joints of the body. Therefore, until model validity is improved, determining muscle activation levels from the neck muscles using EMG as an indicator of mechanical loading is the most appropriate tool to further investigate neck loads in high performance combat pilots. Further, comparing these EMG signals to those recorded during specific neck strengthening exercise may provide a useful tool in the implementation of neck strengthening programs to prevent or rehabilitate neck injuries suffered during high +Gz aerial combat manoeuvres. The limitation of examining EMG data alone however, is that estimations of loading on the passive structures of the cervical spine whilst performing such exercises cannot be determined.

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CHAPTER 5

NECK EXERCISES COMPARED TO MUSCLE ACTIVATION DURING AERIAL COMBAT MANOEUVRES*

Abstract

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. 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 +Gz levels and four head positions. Surface electromyography (EMG) from selected neck and shoulder muscles was recorded in both activities. Muscle activation levels recorded during the three elastic band exercises were similar to in-flight EMG collected at +1 Gz (15% MVIC). EMG levels elicited during the 50% resistance machine exercises were between the +3 Gz (9 – 40% MVIC) and +5 Gz (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 Gz. Thera-Band exercises could possibly be useful to pilots who fly low +Gz missions whilst 50% resistance machine mimicked neck loads experienced by combat pilots flying high +Gz ACM. 70% and 90% resistance machine intensities are known to optimise maximal strength but should be administered with care because of the unknown spinal loads and diminished muscle force generating capacity after exercise.

** This chapter has been submitted for publication.*

Introduction

Both general exercises such as whole body or aerobic exercise, as well as specific exercises targeting the neck musculature have shown positive evidence in the prevention and rehabilitation of spinal pain (ie. neck pain and back pain) (14, 16). Recent research has indicated that performing specific neck conditioning exercises can significantly increase neck muscle strength (5), and strength and endurance (1) when compared to general exercises (8). Furthermore, a program of specific neck conditioning exercises has been shown to increase neck strength and decrease neck pain in both the short (up to 5 weeks) (6) and long term (up to 12 months) (24, 30) in both women and men.

High performance combat pilots are routinely exposed to high mechanical loads in non-neutral head positions and in moderate +Gz levels (11, 12, 19) and this may be the predominate cause of the high occurrence of neck injury and pain in this population. To decrease the incidence of neck injury and pain in combat pilots it has been suggested that specific neck strengthening exercises may have an important role (3, 7, 11, 19, 20). Neck strength increases are limited during the initial exposure to the moderate +Gz 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 +Gz-related loading. Furthermore, there may be a need for more experienced pilots, who are routinely exposed to moderate +Gz environment, 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 periodisation involves manipulating these variables to optimise 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 centres. Conversely, elastic

band latex tubing (Thera-Band, Hygenic Corporation, Akron, OH) is inexpensive, as well as being highly portable. Elastic band tubing is available in colour-coded bands of varying thickness, providing changes in resistance and thus theoretically increasing muscle loading. The exact difference in resistance provided by the tubing is dependent upon 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).

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 characterised 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 +Gz 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 +Gz and non-neutral head positions. Therefore, 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 manoeuvres (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

Firstly, to provide the neck muscle activation data during specific neck exercises, eight male asymptomatic non-pilots (mean (SD), age 23.4 ± 5.1 yrs, height 1.72 ± 0.10m and mass 71.3 ± 14.7 kg) were tested. Secondly, 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 yrs, height: 1.78 ± 0.04m, weight: 82.5 ± 8.4kg, flying time: 375 ± 23 hours) and one fast jet instructor (45yrs, 1.76m, 80kg, 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 and these can be found elsewhere (19). Ethical and technical approval for the study was obtained from the Australian Defence 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

Specific neck exercise testing was undertaken on two different days with subjects attending a familiarisation and neck strength testing session on the first day. Sub-maximal 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 one-week of the first session. Prior to testing, a warm-up consisting of two sets of 12 repetitions of unloaded contractions in each of the three 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 normalisation (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%) whilst 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 customised 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 customised 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 -one-two- for the concentric phase and -three-four- 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 randomised within each modality. To avoid excessive fatigue, two minutes rest was given between each trial.

Elastic band tubing of 70cm 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 minimise 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%.

Electromyography Procedures

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 summarised 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) – 10mm 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 fibres (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 fibres.

Excess body hair was removed and the area was abraded then cleaned with an alcohol swab. Pairs of 12mm diameter Ag-AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN, USA) were adhered to the skin with a 20mm centre-to-centre distance along the muscle fibre orientation. An impedance meter was then used to ensure an impedance reading of $<10k\Omega$ 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 1000Hz and were amplified using a Grass amplifier system (Grass Instrument Co. Warwick, RI) (bandpass frequency, 10-450Hz; input impedance, $<5k\Omega$). The single 25mm diameter retro-reflective marker placed on the apex of the head was tracked for five seconds by a five camera opto-electronic Motion Analysis System (Motion Analysis Company, Santa Rosa, CA) operating at 120Hz. Data were automatically digitised 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 maximum voluntary isometric contractions (MVICs) for the purpose of EMG data normalisation 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 five second 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 customised LabVIEW V7.1 (National Instruments Inc., Texas, USA) program. Raw EMG data were then demeaned, high-pass filtered at 15 Hz to remove any movement artefact, full wave rectified and low pass filtered at 4Hz 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-msec 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 verbalising each +Gz level and head position combination. The beginning of each +Gz/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 synchronised kinematic data. To generate kinematic data (from the marker positioned on the head) at the same time base as the EMG data (ie. 1000Hz), a cubic spline was used. The sub-divided EMG data were then time normalised (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 was used, and in lateral bending only the posterolateral electrodes was 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 +Gz 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 activations 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 calculated 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 (Chicago, IL, USA) 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 to activations elicited during flexion and extension exercises. Table 10 outlines these data.

Table 10

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

Figure 16 demonstrates that increases in the level of neck muscle activation during selected ACM were evident with increasing +Gz with the exception of the neck extensors where the maximum was marginally higher at +3 Gz (54% MVIC) compared to +5 Gz (48% MVIC) ACM. The neck flexors displayed the greatest range of neck muscle activation during flight (9% - 83% MVIC at + 5 Gz) 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 (Figure 16). 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 to 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 Gz values for all muscles. Further, EMG levels elicited during 50% resistance machine intensity/modality were between the +3 Gz 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 to the upper limit of the +5 Gz 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 Gz and 90% was at the lower limit of +5 Gz. Only activation levels in SCM at +5 Gz exceeded the activations elicited during 70% and 90% exercise.

Discussion

Neck injuries and pain in combat pilots are commonplace and these injuries have been suggested to be caused by the repetitive exposure to combinations of hyper-gravity 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 to 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 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). These findings add credence to the suggestions 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

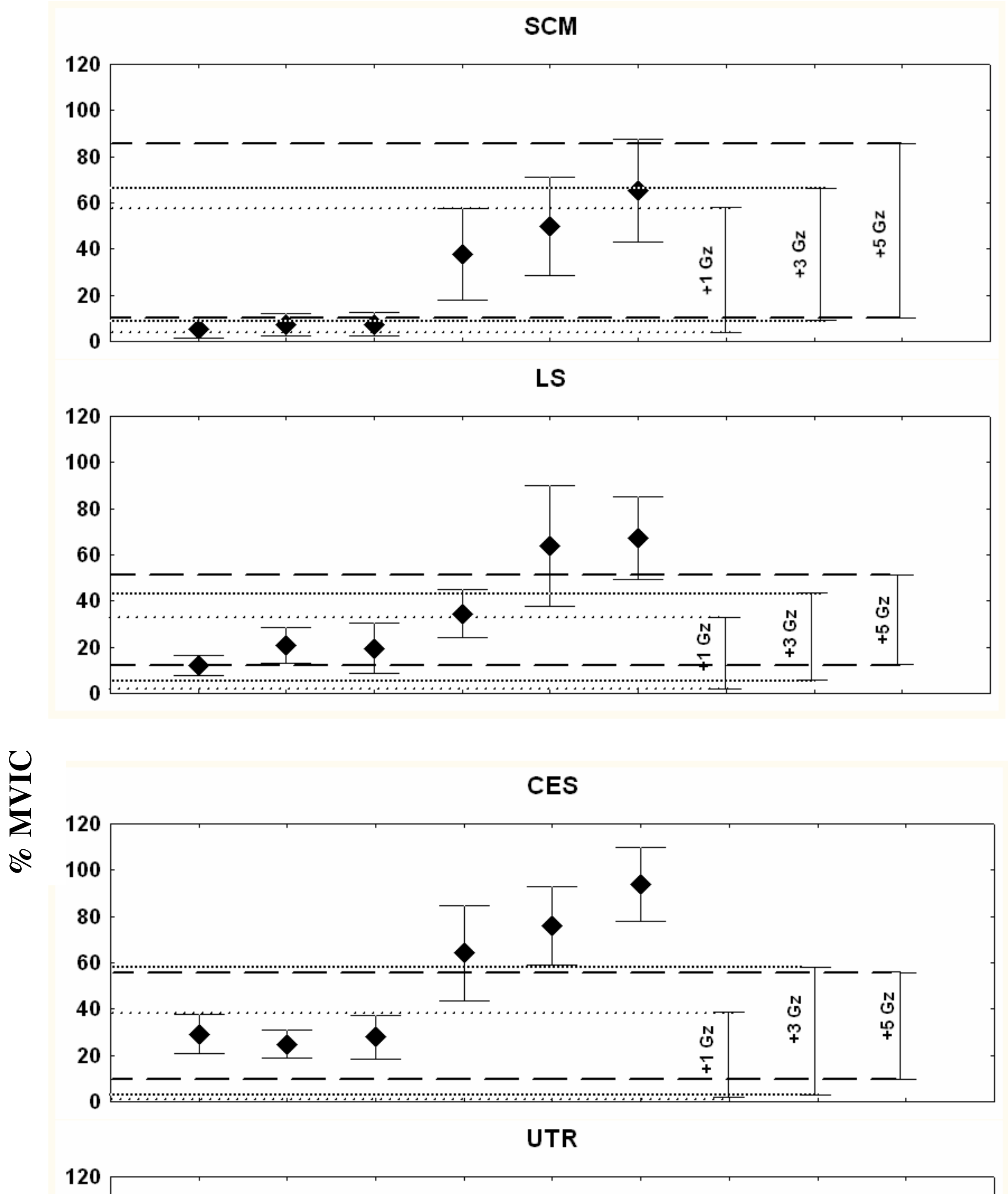
SCM
LS
CES
UTR
% MVIC
120
100
80
60
40
20
0
+1 Gz
+3 Gz
+5 Gz

Figure 16. 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 were obtained during Neutral head position and maximum activation obtained during Check-6 head position.

....	Represents minimum and maximum muscle activations during +1 Gz ACM
....	Represents minimum and maximum muscle activations during +3 Gz ACM
— -	Represents minimum and maximum muscle activations during +5 Gz ACM

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 Gz head positions as well as Neutral at +3 Gz and +5 Gz 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 Gz ACM's. This finding suggests that specific neck muscle exercises using elastic band may be useful for pilots who fly low +Gz missions or tend to keep their head in a more neutral position. This may apply to transport, bombing 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 +1Gz. 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 recommend that such an exercise be included into specific conditioning programs for ACM preparedness in combat pilots.

"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 uni-axial 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 tri-axial movement of the neck in-flight. This may be a direction for future research.

Periodisation 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 males (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 to 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 +Gz neck injury. Conversely, neck muscle activations recorded from both the 70% and 90% resistance machine modalities were above those values recorded at +5 Gz in all neck muscles examined except SCM (Figure 1). Such exercises could be useful as overload intensities, to increase neck strength above that experienced in-flight. Conditioning of muscle based upon 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 optimise 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, inter-vertebral discs and ligaments are unknown when such loads are applied. Further, decreases in muscle function have been reported immediately, and up to 33 hours 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 +Gz phase of their training

as these exercises may diminish the ability of their neck muscles to withstand the high loads of high +Gz ACM. Combat ready pilots should also be aware of this issue when performing such neck exercises during a maintenance phase of training.

A possible limitation of this study may be the use of two dissimilar subject cohorts. However, 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). Furthermore, the dependent variable in this investigation was normalised neck muscle activation and this can be used to compare between individuals and muscles (11, 18, 27).

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, the addition of these exercises as part of a regular neck strengthening routine needs 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. There should be some consideration towards a properly periodised and supervised training regime including the exercises examined in this study. Such a program should be implemented with consideration to flight duties. The appropriate volume of exercise required to elicit a training effect, and the mechanical loads created on the cervical spine during resistance machine and elastic band modality exercises would provide an avenue for future research.

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CHAPTER 6

CONCLUSIONS

As clearly shown in the literature reviewed in this investigation, neck pain and injury is a common occurrence in high performance combat pilots (HPCP) in Air Forces around the world (eg. 7, 17). Often, neck pain in HPCP can result in restricted movement, loss of functionality, lost work days and even the shortening of their flying careers (7, 11). The cause of neck pain and injury in HPCP is normally attributed to exposure to the unavoidable high mechanical loading of the neck and its passive structures in non-neutral head postures and in moderate to high +Gz levels (7, 10, 16).

Specific neck conditioning exercises have been shown to significantly increase neck strength and decrease neck pain in different populations (5, 12, 13, 18). Similar increases in neck strength were also recorded when such exercises were administered to HPCP (1, 19). As such, many researchers have advocated the implementation of such neck strengthening regimes to decrease neck injuries suffered by HPCP (1, 7, 16, 17). This would appear to be a highly desirable and cost effective manner in which to both prevent and manage this unique occupational hazard.

The proper design of exercise programs is important in order to optimise the desired outcomes of these training regimes. Appropriate selection of acute training variables such as exercise specificity, intensity, duration and loading (specifically overload) are known to be important considerations in increasing muscle strength (2). These variables are usually manipulated to provide the body with an overload stimulus. The most effective variable in increasing muscular strength however, is considered to be loading (20). Since trainee pilots have been shown to non-significantly increase neck strength by initial exposure to +Gz (4), additional stimuli are needed to cause overload and as such, further increase and maintain neck strength. Further, it may be possible for HPCP to prevent or delay injury with the use of specific neck strengthening exercises.

Therefore, the overall aim of this doctoral investigation was to examine the suitability of specific neck strengthening exercise in preventing and rehabilitating neck injuries sustained by HPCP during moderate to high +Gz ACM. This overarching aim

of the thesis was investigated by conducting four inter-linked studies that were necessary due to there being clear gaps in the literature. A brief description of each study and the relevant findings are discussed below in turn.

The first study (15) investigated the reliability of field and laboratory methods in attaining a sub-maximal and maximal voluntary isometric contraction (MVIC) of the neck and shoulder muscles for the purpose of EMG data normalisation. It posed these questions:

- What is the best method of obtaining a reliable reference EMG signal that could be used for normalisation of EMG data collected from the neck?
- Is a field based method of EMG normalisation as reliable as traditional laboratory based methods?
- For EMG normalisation purposes, are sub-maximal normalization contractions as reliable as maximal contractions?

In this study it was found that a reliable reference EMG signal could be obtained from the neck muscles for the purpose of normalisation in both field and laboratory studies. Furthermore, MVIC's elicited from the devices examined in this study proved to be more reproducible when compared to sub-maximal normalisation methods.

The second study (16) examined in-flight neck and shoulder muscle EMG in addition to quantifying head kinematics during selected ACM in HPCP. These data were collected for two reasons; firstly, to provide a description of mechanical load and secondly, to be used as input into a commercially available graphically based EMG-driven musculoskeletal model of the cervical spine (21). The results from the study showed that head stabilisation is an important function of the neck and shoulder musculature in ACM. Further, 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.

The third study was undertaken to examine the validity of the abovementioned neck model (21). Specifically, subject-specific data were collected then the model's output (neck torque) was compared to a gold standard namely, neck torque output

collected from an isokinetic dynamometer. These subject-specific data which were implemented into the model included; neck muscle morphometry derived from MRI scans of the cervical spine as well as muscle activation data from the deep neck muscles. Deep neck muscle activation data was collected to examine whether partially "driving" the model using these deep muscles improved the validity of the model. The studies main research question was:

- Can isometric moments be accurately predicted by an EMG-driven musculoskeletal model of the cervical spine?

The results of this validation study revealed that the model was not sufficiently valid at this stage to answer the questions related to loading of the passive structures of the cervical spine in ACM and specific neck strengthening exercises. This is not to say however, that this method does not hold promise in future investigations. Consequently, EMG was chosen as the appropriate tool to investigate neck loading in this investigation.

Finally, neck and shoulder muscle activation recorded during specific neck strengthening exercises (three intensities in each of the Thera-band and Cybex modalities) were compared to neck and shoulder muscle EMG previously measured in-flight in Study 2. Results from this study showed that neck muscle activation levels recorded during some specific neck exercises fall within the range of neck muscle activations recorded when HPCP perform ACM. The reported exercise modalities and intensities examined in this study also provided a continuum of exercise training for specific neck strengthening with the aim of preventing and rehabilitating neck injuries experienced by HPCP.

Limitations of the Research

The main limitation of this investigation was that EMG of the neck and shoulder musculature was used as the main investigative tool to examine neck loading in-flight as well as during specific neck strengthening exercises. Unfortunately this method of investigation does not allow researchers an insight into individual muscle forces, reactive forces on passive tissue and bone-on-bone forces in the cervical spine. A valid

musculoskeletal model of the cervical spine would allow these quantifications. However, such a model was shown to be of insufficient validity for the application of this investigation.

Another limitation of this investigation is that the suitability of specific neck strengthening exercises compared to in-flight neck loads was judged with regard to EMG activation in this investigation. No training (intervention) studies were conducted to evaluate the usefulness of these exercises in preventing and rehabilitating neck injuries in HPCP. The results of this investigation do however give a very clear indication of exercise loading for the use in future training studies such as that outlined by Alricsson et al (1).

Future Research Directions

Cervical Spine Musculoskeletal Modelling

Graphically based, EMG-driven musculoskeletal modelling of the cervical spine is potentially a very powerful tool to investigate the pathomechanics of neck injury in HPCP. However, obtaining adequately valid neck torque predictions from the model proved elusive in this investigation. Optimising model parameters such as the muscle PCSA to force conversion factor, and muscle force-length characteristics with the aid of externally measured torque output with the aid of an isokinetic dynamometer has been an approach utilised in other models in the knee (14) and elbow (3). The inclusion of such procedures would be an intuitive next step to improve model validity. Further, validation of the model in movements other than flexion and extension as conducted in this study, such as head rotation, as well as lateral bending may improve the proposed model parameter optimisation procedures (14).

Currently, the neck model can only predict neck torques in static and quasi-static head postures (21). This limits its application to many situations where dynamic head movement may be part of the investigation. This is because the model lacks muscle architectural detail such as segmental moment of inertia parameters and muscle radius of gyration data (9, 21). Dynamics muscle models are reliant on the input of such data to accurately predict torque-time histories. These data, although available (8), are currently not provided in sufficient enough detail for input into the model (9). However, modern imaging techniques such as MRI exist therefore, such information can be obtained and

these techniques have been successfully utilised to examine other joints in the body (3, 6). The possibility of implementing these methods to further the development of the neck model examined in this should be considered.

Intervention Involving Specific Neck Strengthening Exercise

Specific neck conditioning exercises have previously been proposed to be important for increasing neck strength in HPCP and possibly preventing neck injury (7). Study Four in this doctoral investigation showed that a number of the specific neck strengthening exercises examined were specific to the neck muscle activations recorded in-flight during ACM. Thus, the aspect of training specificity has been fulfilled. However, other training variables like optimal number of repetitions and periodisation of training which have been shown to optimise strength gains (eg. 20) were not examined in this investigation. Future studies should utilise the findings of this investigation in intervention studies to allow the optimal training of neck strength for training time. If such studies were specific to training HPCP, they may be split into two separate investigations. Firstly, the optimisation of attainment of neck strength by new recruits with a possible implementation of a targeted neck training regime during initial flight training where most low +Gz forces are encountered. Secondly, further studies should investigate the maintenance of adequate levels of neck strength by operationally active HPCP. These may include training studies to investigate periodised training schedules that allow for operational readiness but do not compromise immediate neck strength as well as the implementation of portable strengthening devices that HPCP can use in the field during extended periods of operational deployment.

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Appendices

Appendix 1: Human Ethics Approval

PE 2000/19712
ADHREC 220/00
DHSB /2004

Mr Kevin Netto
Edith Cowan University
School of Biomedical & Sport Science
100 Joondalup Drive
JOONDALUP WA 6027

Dear Mr Netto

AUSTRALIAN DEFENCE HUMAN RESEARCH ETHICS COMMITTEE (ADHREC) PROTOCOL 220/00: INJURY PREVENTION IN RAAF FIGHTER PILOTS: A NECK STRENGTHENING PROGRAM FOR HIGH PERFORMANCE PILOTS

1. ADHREC has considered your protocol and has cleared your project to proceed. Please note that ethical clearance from ADHREC does not automatically confer access to ADF personnel; this will have to be sought from the relevant military commanders.

2. Your protocol has been allocated **ADHREC Protocol Number 220/00,** and this number should be quoted in all correspondence. Your protocol has been approved for a period of three years. If your research is to continue over the three year approval time, ADHREC approval for an extension is to be sought in writing.

3. ADHREC requires you to provide six-monthly progress reports, the first being due on 1/5/05. ADHREC's compliance with the NHMRC *National Statement on Ethical Conduct in Research Involving Humans* requires that your progress reports include, where applicable, comment on: the security of your records; compliance with the approved consent procedures and documentation, and compliance with any other special conditions that ADHREC may have required.

4. If your protocol requires any modification, ADHREC approval must be sought in writing, detailing all modifications required.

5. For Clinical trials, ADHREC is to be notified in writing of all **Serious Adverse Events within 72 hours of the event occurring**.

6. For completeness, would you please sign the enclosed researcher's agreement and return it to me at your convenience. I have also enclosed ADHREC's Guidelines for Volunteers, a copy of which is to be given to each study participant.

The Committee wishes you well with your research. Please contact me if I can be of any assistance.

Yours sincerely,

DR R.A LANDY
Executive Secretary
Australian Defence Human Research Ethics Committee
CP2-7-068
Campbell Park Offices
CANBERRA ACT 2600

Tel (02) 62663837
Fax (02) 62664982
E-mail: ADHREC@defence.gov.au

06 December 2006

Annex:
A. ADHREC *Researchers Agreement*
B. ADHREC *Guidelines for Volunteers*

HUMAN RESEARCH ETHICS COMMITTEE

For all queries, please contact:
Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: 6304 2170
Fax: 6304 2661
E-mail: research.ethics@ecu.edu.au

22nd June 2004

Mr Kevin Netto (Student [redacted])
[redacted]

Dear Mr Netto

PROJECT CODE	02-77
PROJECT TITLE	Cervical neck loads in high performance combat pilots during aerial combat manoeuvres and selected neck strengthening exercises
CHIEF INVESTIGATOR	Mr K Netto

Thank you for your recent request for an extension on the above application.

I am happy to inform you that an extension for the above project to the 31st December 2005 has been approved and noted by the Human Research Ethics Committee.

Please continue to keep us informed of any changes to your research project.

Once again, with best wishes for success in your work.

Yours sincerely

Kim Gifkins
EXECUTIVE OFFICER
Phone 6304 2170
Fax: 6304 2661
Email: research.ethics@ecu.edu.au

Attachment – Conditions of Approval

cc: Dr Agnus Burnett, Supervisor
Mrs K Leckie, Manager Graduate School
Ms R Treloar Cook, Administrative Officer, HDC

Appendix 2: Subject Information Sheet and Documents of Informed Consent

Study 1

Summary

The measures from this study will be used to develop and validate a model of the cervical spine. You will be asked to perform a number of isometric and slow dynamic contractions in a dynamometer. Eight pairs of electrodes (electromyography) will be attached to various sites on your neck. These will measure the muscular activity when you perform the contractions.

Risk and ethical considerations

As the number of repetitions for each head movement are low, you should not experience any muscle soreness. You will need to be prepared for electromyography by shaving your neck and slight exfoliation of the skin.

No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance within the group being compared. You are therefore not in competition with any other individuals in the study and will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject. You will be free to withdraw from this study at any stage and for any reason without prejudice.

Requirements

As the study involves an exercise protocol, it is required that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns

about this research, or would just like to speak to an independent person, you may contact Dr. Paul Laursen [redacted]

Yours Sincerely,

Kevin Netto BSc. (Hons) (PhD candidate)

School of Exercise, Biomedical and Health Sciences

Edith Cowan University

100 Joondalup Drive, Joondalup WA 6027

Phone: 6304 5860 E-mail: k.netto@ecu.edu.au

Declaration

I ____ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant ________________________________ Date _______________________

Investigator _______________________________ Date _______________________

Study 2

Summary

The study will investigate the neck muscular activations in-flight during various flight manoeuvres. It will also quantify head positions adopted in-flight. The results will be compared to similar measures taken from neck strengthening exercises, allowing the specificity of these exercise to be judged.

You will be asked to perform a number of specific flight manoeuvres. Eight electrodes (electromyography) will be attached to various sites on your neck. These will measure the muscular activity when you perform the manoeuvres. A portable data logger will record these readings.

After the flight, you will be asked to view the flight (HUD) video and place your head in similar position that you adopted in-flight. An electromagnetic tracking device will be secured to the front of your head and on your chest, allowing head positional measures to be made.

Risk and ethical considerations

You will need to be prepared for electromyography by shaving your neck and slight scaling of the skin. The electromyography data logger is purely a recording device and as such will not interfere with any of the electronics or avionics of the aircraft.

No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance between another group being compared. You are therefore not in competition with any other individuals in the study and will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject. You will be free to withdraw from this study at any stage and for any reason without prejudice.

Requirements

It is requirement that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing. Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would just like to speak to an independent person, you may contact the Dr. Angus Burnett on telephone (9400 5860).

Kevin Netto BSc. (Hons) (PhD candidate)
School of Exercise, Biomedical and Health Sciences, Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
Phone: [redacted] E-mail: k.netto@ecu.edu.au

CONSENT FORM

Declaration

I, ____ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

I, ____ give my consent to participate in the project mentioned above on the following basis:

I have had explained to me the aims of this research project, how it will be conducted and my role in it.

I understand the risks involved as described above.

I am cooperating in this project on condition that:

* the information I provide will be kept confidential

* the information will be used only for this project

I understand that:

* there is no obligation to take part in this study,
* if I choose not to participate there will be no detriment to my career or future health care,
* I am free to withdraw at any time with no detriment to my career or future health care.

I have been given a copy of the information/consent sheet, signed by me and by the researcher (Kevin Netto) to keep.

Signature of Volunteer (Please also initial bottom of each page)

____

Name in Full

____

Date

____

Signature of Researcher

____

Name in Full

____

Date

____

Should you have any complaints or concerns about the manner in which this project is conducted, please do not hesitate to contact the researchers in person, or you may prefer to contact the Australian Defence Human Research Ethics Committee or the University of Wollongong/Illawarra Area Health Service (IAHS) Human Research Ethics Committee at either of the following addresses:

Executive Secretary
Australian Defence Human Research Ethics Committee
CP2-7-66
Department of Defence
CANBERRA ACT 2600
Telephone: (02) [redacted] / Facsimile: [redacted]

[redacted]

Study 3, Part 1

Summary

This study deals with obtaining a number of measurements from your cervical spine region. These include measures of muscle and tendon length, cross-sectional area and bone structure.

A magnetic resonance imaging (MRI) scan will be taken of your neck from your eye to shoulder level. This scan will be used to obtain the measures.

Risk and ethical considerations

MRI does not produce any radiation therefore there is no risk to the subject. There is however, the chance that you might experience some claustrophobia while in the scanner. A trained radiographer who has experience with this sort of situation will be in attendance at all times and the scan can be terminated immediately if you feel too uncomfortable No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance within the group being compared. You will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject. You will be free to withdraw from this study at any stage and for any reason without prejudice.

Requirements

It is required that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would just like to speak to an independent person, you may contact Dr Fiona Naumann on telephone (9400 5012).

Yours Sincerely,

Kevin Netto BSc. (Hons) (PhD candidate)

School of Exercise, Biomedical and Health Sciences

Edith Cowan University

100 Joondalup Drive, Joondalup WA 6027

Phone: 6304 5860 E-mail: k.netto@ecu.edu.au

Declaration

I ____ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant ___________________________ Date ___________________

Investigator ___________________________ Date ___________________

Study 3, Part 2

Summary

The measures from this study will be used to develop and validate a model of the cervical spine. You will be asked to perform a number of isometric and slow dynamic contractions in a dynamometer. Eight pairs of electrodes (electromyography) will be attached to various sites on your neck. These will measure the muscular activity when you perform the contractions.

Risk and ethical considerations

As the number of repetitions for each head movement are low, you should not experience any muscle soreness. You will need to be prepared for electromyography by shaving your neck and slight exfoliation of the skin.

No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance within the group being compared. You are therefore not in competition with any other individuals in the study and will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject. You will be free to withdraw from this study at any stage and for any reason without prejudice.

Requirements

As the study involves an exercise protocol, it is required that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would just like to speak to an independent person, you may contact Dr. Paul Laursen (6304 5012).

Yours Sincerely,

Kevin Netto BSc. (Hons) (PhD candidate)

School of Exercise, Biomedical and Health Sciences

Edith Cowan University

100 Joondalup Drive, Joondalup WA 6027

Phone: 6304 5860 E-mail: k.netto@ecu.edu.au

Declaration

I ____ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant _______________________________ Date ______________________

Investigator ______________________________ Date ______________________

Study 4

Summary

The study will investigate the muscular force created in the neck during various neck strengthening exercises. The results will be compared to similar in-flight measures taken from pilots during aerial combat manoeuvring.

You will be asked to perform a number of neck strengthening exercises. Eight electrodes (electromyography) will be attached to various sites on your neck. These will measure the muscular activity when you perform the exercises.

Risk and ethical considerations

As the number of repetitions for each head movement are low, you should not experience any muscle soreness. You will need to be prepared for electromyography by shaving your neck and slight exfoliation of the skin.

No direct comparisons between different individuals participating in the study will be made at any stage of the testing. Analysis of data will be made on a group basis with means and variance between another group being compared. You are therefore not in competition with any other individuals in the study and will in no way be made to feel that your results are inadequate or incorrect.

All personal information and test results recorded will remain confidential and will not be used for any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject. You will be free to withdraw from this study at any stage and for any reason without prejudice.

Requirements

As the study involves an exercise protocol, it is required that you be healthy at the time of testing. For this reason, you will be asked to complete a medical questionnaire prior to the commencement of testing.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would just like to speak to an independent person, you may contact the Dr. Paul Laursen (6304 5012).

Yours Sincerely,

Kevin Netto BSc. (Hons) (PhD candidate)

School of Exercise, Biomedical and Health Sciences

Edith Cowan University

100 Joondalup Drive, Joondalup WA 6027

Phone: 6304 5860 E-mail: k.netto@ecu.edu.au

Declaration

I ____ have read all of the information contained on this sheet, have completed a medical questionnaire, and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant ________________________________ Date ______________________

Investigator ________________________________ Date ______________________

Appendix 3: Medical Questionnaires

Study 1, 3 and 4

The following questionnaire is designed to establish a background of your medical history, and identify any injury and/ or illness that may influence your testing and performance.

Please answer all questions as accurately as possible, and if you are unsure about any thing please ask for clarification. All information provided is strictly confidential.

Personal Details

Name:________________________________ ID number:_________________

Date of Birth (D/M/Y):__________________

Medical History

Have you ever had, or do you currently have any of the following?

If Yes, please provide details

Do you have or have you had any neck or shoulder pain? Y N

____

Have you recently injured your neck or shoulders? Y N

____

Do you have a history of dizziness or fainting? Y N

____

Do you have an irregular heartbeat? Y N

____

Have you suffered a severe headache that was aggravated by straining? Y N

Are you at risk of carotid or coronary artery disease? Y N

Do you have high blood pressure? Y N

Do you suffer from limited pulmonary function? Y N

Is there any other condition not previously mentioned which may affect

your participation in this study? Y N

Lifestyle Habits

Do you exercise regularly? If YES, what do you do? Y N

How many hours per week?

Do you smoke tobacco? If YES, how much per day? Y N

Do you consume alcohol? If YES, how much per week? Y N

Declaration

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Name:________________________________ Date:________________

Signature:______________________________

Study 2

The following questionnaire is designed to establish a background of your medical history and identifies any injury and/ or illness that may influence your testing and performance.

Please answer all questions as accurately as possible, and if you are unsure about any thing please ask for clarification. All information provided is strictly confidential.

Personal Details

Name:________________________________

Date of Birth (D/M/Y):__________________

Height: _________________ m

Weight: _________________kg

Approx Flying Hours: ___________________

Medical History

Have you ever had, or do you currently have any of the following?

If Yes, please provide details

Do you have or have you had any neck or shoulder pain? Y N

____

Have you recently injured your neck or shoulders? Y N

____

Do you have a history of dizziness or fainting? Y N

____

Do you have an irregular heartbeat? Y N

____

Have you suffered a severe headache that was aggravated by straining? Y N

____

Are you at risk of carotid or coronary artery disease? Y N

____

Do you have high blood pressure? Y N

____

Do you suffer from limited pulmonary function? Y N

____

Is there any other condition not previously mentioned which may affect your participation in this study? Y N

____

Lifestyle Habits

Do you exercise regularly? If YES, what do you do? Y N

____

How many hours per week?

____

Do you smoke tobacco? If YES, how much per day? Y N

____

Do you consume alcohol? If YES, how much per week? Y N

____

Declaration

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Signature:______________________________ Date:________________