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The Effect of Moderate +Gz on Cervical Muscle Strength of RAAF Trainee Pilots Flying PC-9 Aircraft

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THE EFFECT OF MODERATE +Gz ON CERVICAL MUSCLE STRENGTH OF RAAF TRAINEE PILOTS FLYING PC-9 AIRCRAFT

By

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USE OF THESIS

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ABSTRACT

External stimulus/loading initiates adaptations within skeletal muscle. Whilst performing flying manoeuvres under +Gz it has been previously found that the cervical area has the highest loading. The purpose of this study was to examine cervical muscle response to moderate +Gz force (+4-6Gz) loading generated during RAAF pilot training. Cervical muscle strength was monitored in nine RAAF pilots completing an eight-month flight training course and ten controls matched for gender, age, height and weight. Cervical muscle strength and range of movement were measured at baseline and at eight months using the Multi-Cervical Rehabilitation Unit (Hanoun, Canada). Also measured, using EMG, was the activation of sternocleidomastoid and erector spinae muscles for a test pilot during simulated flight training. The statistical procedure used was a comparison in the difference between the pilots and control subjects for baseline and post-testing in neck strength and range of movement using an unpaired t-test. Statistical significance was accepted at $p<0.05$. Results indicated that an increase in neck strength was limited to the pilot's neutral flexion position. No strength changes were recorded in any other site in the pilots or for the controls. Two significant changes occurred in range of movement; a decrease in flexion and an increase in lateral flexion to the left in the control group. EMG results found that the sternocleidomastoid (97.8%) is used predominantly when executing a right twist head movement whilst completing a +3Gz left turn in the Pilatus PC-9. When executing a series of manoeuvres it was found the erector spinae was activated at a high level (89.5% MVC). Fatigue in this area may occur over time making this a priority area for strengthening as it may be highly susceptible to injury. These findings support the notion that exposure to +Gz has limited effect on increasing

cervical muscle strength. Neck strength training outside of the aircraft may be warranted in order to prevent neck injuries whilst flying.

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GLOSSARY OF ABBREVIATIONS

+Gz	Positive G-forces
-Gz	Negative G-forces
ADMEC	Australian Defence Medical Ethics Committee
C1	Cervical 1
EMG	Electromyography
ES	Erector Spinae muscle
ICC	Intra-Class Correlation
IEMG	Surface-integrated EMG
MCU	Multi-Cervical Unit
MVC	Maximal Voluntary Contraction
RAAF	Royal Australian Air Force
ROM	Range of Movement
SCM	Sternocleidomastoid muscle
SEM	Standard Error of Measurement
T4-5	Thoracic 4-5
TEM	Technical Error of Measurement
WA	Western Australia

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

When pilots are exposed to high positive G-forces (+Gz), it is common for cervical injuries to occur (Albano & Stanford, 1998; Drew, 2000; Hamalainen, Toivakka-Hamalainen, & Kuronen, 1999; Hamalainen & Vanharanta, 1992; Kikukawa, Tachibana, & Yagura, 1994; Knudson, McMillan, Doucette, & Seidel, 1988; Newman, 1997a, 1997b; Petren-Mallmin & Linder, 1999). According to Hamalainen and Vanharanta (1992) when +Gz are directed from the head to the feet, high stress is placed on the cervical spine. In order to maintain an upright position of the head under +Gz, the cervical erector spinae muscles must be activated (Hamalainen & Vanharanta, 1992). The occurrence of cervical injuries in high performance pilots is often due to insufficient strength of the cervical muscles in supporting the head during +Gz induced loading. If a pilot's cervical strength is weak before entering flight training, they may be more susceptible to injury while executing flying manoeuvres under high +Gz (Newman, 1997a).

Acceleration occurs during plane flight, and is defined as a change of velocity in magnitude and/or direction and is measured in G units (Reinhart, 1996). The forces produced by acceleration affect the body in all directions although it appears most of the forces occur from head to foot (+Gz), down the vertical axis of the body (Reinhart, 1996). These forces are referred to as G-forces and the type (positive or negative), intensity, and duration of a G-force can have an effect on the pilot (Reinhart, 1996).

A +Gz occurs when the pilot is pushed downward into his/her seat by the accelerated forces (Reinhart, 1996). If +Gz are sustained, blood begins to pool in the feet, and blackout can occur in response to insufficient blood to the brain (Reinhart, 1996). According to Ernsting and King (1988), pilots can be exposed to positive accelerations of +5-7Gz for 10-40 seconds, and even as high as +8-10Gz for up to 60 seconds. It appears that human tolerance to +Gz forces has become the limiting factor to aircraft performance (Ernsting & King, 1988). The body is less tolerant to negative G-forces (-Gz) and is limited to around -3Gz (Reinhart, 1996). –Gz are generally experienced during aerobatic flying. The feeling of experiencing –Gz is similar to going over the top of a roller coaster ride, as blood is forced to the head, vision begins to redden and redout occurs (feeling of eyes popping out) after approximately five seconds (Reinhart, 1996).

The incidence of neck injuries in high performance aviators is high and appears to be increasing as aircraft capabilities improve (Royal-Australian-Air-Force, nd). Several studies have found moderate to high percentages of pilots reporting acute spinal injuries, especially neck pain (Albano & Stanford, 1998; Drew, 2000; Newman, 1997a, 1997b). A study of 52 Royal Australian Air Force (RAAF) F/A-18 Hornet and MB326H Macchi fighter pilots found that 85% of pilots reported neck injuries (Newman, 1997a). Most of the injuries were muscle sprains, with 38% of the surveyed pilots reporting that their neck injury interfered with the completion of their mission (Newman, 1997a). Of these pilots 27% sought medical attention and a further 17% of the pilots were taken off flight duties for approximately two weeks due to their neck injury (Newman, 1997a). The pilots in Newman's (1997a) study were generally pulling in excess of +5.5 Gz (MB326H Macchi) and +7.5 Gz (F/A-18 Hornet) and it was found that the pilots pulling the higher +Gz were susceptible to a neck injury than the pilots pulling the lower +Gz.

Drew (2000) found 54% of pilots reported neck pain and a percentage of those aviators described the neck symptoms as limiting their flying performance, especially when exposed to high +Gz air combat manoeuvring. Vanderbeek's (1988) study found 50.6% of the high performance pilots suffered some type of acute neck injury. Knudson, McMillan, Douchette and Seidel (1988) found an even higher percentage (74%) of F/A-18 aviators reporting neck pain, due to the high +Gz of the aircraft. Kikukawa, Tachibana and Yagura (1995) surveyed F-15 pilots in Japan and 89.1% of the pilots surveyed reported neck pains related to flying.

Albano and Stanford (1998) studied F-16 pilots and found the prevalence of neck injuries over one year to be 56.6% and over an F-16 career to be 85.4%. Albano and Stanford (1998) also stated that for every 100 hours of flying, the risk of injury increased by 6.9%. From these studies it may be concluded that the prevalence of neck injuries for high performance aviators undergoing moderate to high +Gz is high. Prevention of these injuries should be of high priority to both pilots and their superiors.

There has been three major risk factors identified for cervical +Gz injuries in high performance aviators. These are repeated exposure to +Gz forces above +4Gz, unpreparedness for high +Gz manoeuvres and off-centre positioning of the head during +Gz manoeuvres. The first risk factor is repeated exposure to +Gz forces above +4Gz (Albano & Stanford, 1998; Hamalainen, Vanharanta, & Bloigu, 1994; Hamalainen, Vanharanta, & Knusela, 1993). Albano and Stanford (1998) stated that there is an increased risk factor for cervical +Gz injuries when incurring repeated exposure above +4Gz, because as flight time increased so did the opportunity for injuries to occur. This finding suggests that muscle fatigue is a contributing factor for neck injury in pilots. In light of this evidence muscle endurance needs to be examined in conjunction with peak muscle strength to assess if they are sufficient to meet flight demands. Electromyography (EMG) data is an effective method of acquiring information about muscle activation and fatigue and will be used in this study. Cervical injuries during flight would not be expected by the trainee pilots in the current study as they were not flying for sustained periods of +4Gz and above during the course.

Also seen as a risk factor for neck injury is the unpreparedness for high +Gz manoeuvres (Aho, Hamalainen, & Vanharanta, 1990; Andersen, 1988; Knudson et al., 1988; Schall, 1989). Andersen (1988) reported a flight surgeon was injured due to being unaware of the manoeuvres of his flight commander. The cervical spine can be vulnerable to injury if support from the adjacent tissues is insufficient to withstand the +Gz loading, which may occur when the person involved is unaware of an up and coming manoeuvre (Andersen, 1988). Once again, an injury of this nature would not be expected during flight-training as the Pilatus PC-9 is not flown during training in a manner capable of pulling or sustaining +Gz high enough to cause this type of injury.

The third major risk factor is the off-centre positioning of the head during +Gz manoeuvres (Aho et al., 1990; Andersen, 1988; Knudson et al., 1988; Schall, 1989). In particular the check six position of the head has been stated as a high risk position by pilots whilst pulling +Gz (Hamalainen & Vanharanta, 1992; Kikukawa et al., 1994; Knudson et al., 1988; Vanderbeek, 1988). As a pilot turns or twists his/her head the neck muscles lengthen. Under sustained +Gz loading the force exerted onto the neck muscles is greater than when the head is in the neutral position (Hamalainen & Vanharanta, 1992). This results in a higher incidence of injury and is a factor which needs to be addressed in order to prevent these injuries from occurring at the current rate. The trainee pilots were not expected to use the check six position often during flight training and most of the off-centre positions were extension, right and left twists and rotation head movements. The risk of this type of injury arising in the trainee pilots during the low to moderate +Gz flight training was not considered high.

1.2 Significance of the Study

To date, very few studies have looked directly at the impact of +Gz forces on the cervical muscle strength of pilots and the effect this impact has on range of movement (ROM) of their cervical spine (Alricsson, Harms-Ringdahl, Schuldt, & Linder, 2001). These studies have also failed to assess whether or not the strength increases found in the cervical region are in direct response to flying under +Gz as no longitudinal studies have been completed. Previous studies have examined cervical spine degeneration and disc protusion injuries in pilots (Hendriksen & Holewijn, 1999; Petren-Mallmin & Linder, 1999), but research has been limited when examining cervical muscle strength or range of movement responses to flying in high performance pilots (Alricsson et al., 2001).

It is currently unknown whether the natural muscle adaptation of the body to flight is adequate to cope with the +Gz undertaken during flight tasks, or whether specific cervical-muscle training programs need to be introduced to adequately prepare the neck to cope with aerial combat. This study will assist with the body of knowledge in this area, because if natural adaptation in cervical muscle strength of trainee pilots is found to be insufficient to cope with flight demands, then this may be a factor contributing to the high incidence of neck injuries found previously in high performance pilots pulling +4Gz and above (Hamalainen et al., 1999), as these pilots are expected to cope with greater strains on the neck than trainee pilots.

A decrease in range of movement may also be a consequence of long term exposure to flying under +Gz. If a decrease in ROM is found to adversely effect the pilots performance in the air or contribute to neck injuries then further research needs to be intensified in this area. According to Newman (1997a) it was more likely that poor ROM in high performance pilots was a consequence of prior injury, rather than a contributor to the injury occurring. Furthermore, with the use of EMG data, it may be possible to guesstimate the loads placed on the cervical area during flight training. This will give a clearer indication as to whether there is a need for additional training outside of the aircraft.

The career length of high performance pilots is limited, with pilots often being forced to retire prematurely due to injury. Information found in this study will possibly assist pilots in lengthening their careers and also complement further studies into the importance of a specific resistance training program in preventing injuries in high performance pilots. To train a high performance pilot costs hundreds of thousands of dollars. The information found in this study will possibly assist the armed services in retaining pilots in their chosen career for longer, therefore having to train less people and saving themselves, the government and the community money.

1.3 Purpose of the Study

The main purposes of the study are to determine whether the moderate +Gz (+2-6Gz) generated during flight training stimulates an increase in isometric cervical muscle strength and how range of movement in the cervical area may change (if in fact it does) in RAAF trainee pilots. Data from this study will assist researchers in gaining additional information of the effect +Gz loading has on the human body. Another purpose of this study will be to quantify the demands placed on the cervical muscle response during flight using EMG. The study will begin to establish if natural adaptation is adequate or whether strength training may need to be performed outside the aircraft. This may then lead to further research which outlines techniques of preventing injury to the cervical region of pilots, which is commonplace in air forces throughout the world (Kikukawa et al., 1994; Knudson et al., 1988; Newman, 1997a; Vanderbeek, 1988).

1.4 Research Questions

1.4.1 Does moderate (+2-6Gz) loading experienced in a PC-9 aircraft increase the isometric cervical muscle strength of Royal Australian Air Force (RAAF) trainee pilots?

1.4.2 Does moderate (+2-6Gz) loading experienced in a PC-9 aircraft decrease the range of motion of the cervical spine of the RAAF trainee pilots?

1.5 Hypotheses

1.5.1 Moderate +Gz loading will increase the cervical muscle strength of trainee RAAF pilots over an eight-month flight training course.

1.5.2 Moderate +Gz loading will see no change in the range of movement of the cervical spine of the RAAF trainee pilots.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Introduction

There are five main areas within this study which need to be outlined and examined to understand the research questions more clearly. These areas are +Gz forces, muscle loading, muscle strength, range of movement and EMG. Even as we sit, stand or lie, the body is under +1Gz. As a high performance pilot flying aerial manoeuvres the +Gz forces increase dramatically as does the pressure placed on different areas of the body. Studies show the cervical area is highly prone to injury when flying under high +Gz due to the increased loads/strains placed on the cervical area (Albano & Stanford, 1998; Drew, 2000; Hamalainen et al., 1999; Hamalainen & Vanharanta, 1992; Hoek-Van-Dikje, Snijders, Roosch, & Burgers, 1993; Newman, 1997a; Petren-Mallmin & Linder, 1999).

Many studies conclude the cervical region is the most susceptible to injury and recommend a specific neck strength weight-training program to prevent injury (Alricsson et al., 2001; Conley, Stone, Nimmons, & Dudley, 1997a, 1997b; Hamalainen, Heinijoki, & Vanharanta, 1998). However, no study has examined the effect of +Gz loading on the muscles of the body and in particular the cervical area. This information is the first step in understanding the load

+Gz forces place on the body and links to further studies where weight training programs may be necessary.

Few studies (Alricsson et al., 2001) have seen the importance of range of movement to high performance pilots, and the study of cervical range of movement within the general population is also a relatively new area of research (Jordan, Mehlsen, & Ostergaard, 1997). Range of movement is an important area for high performance pilots because they are expected to complete twists, turns and rotations of the head through large ranges in order to execute air combat manouevres.

EMG measurements show researchers and pilots the degree to which muscles are activated and can be compared to the pilot's maximal voluntary contraction (MVC). There have been three studies (Hamalainen & Vanharanta, 1992; Oksa, Hamalainen, Rissanen, Myllyniemi, & Kuronen, 1996; Oksa, Hamalainen, Rissanen, Salminen, & Kuronen, 1999) which have used EMG to register muscle activation of the cervical area. EMG measurements exhibit the strain placed on the muscle and indicates whether the muscles are working above or within their capabilities. If the strain on the muscle is greater than the MVC then an injury may occur (Oksa et al., 1996). The following review gives background into muscle, muscle strength and adaptation, the effects of +Gz on the body, and EMG, range of movement and muscular strength of high performance pilots.

2.2 Anatomy of Skeletal Muscle

To understand the cervical region and how the muscles of the cervical region are strengthened, it is necessary to obtain some background knowledge into the area. There are 660 skeletal muscles in the human body, with the cervical region consisting of 15 muscles (Cailliet, 1991). The muscles of the neck can be divided into two distinct functional groups, the flexors and extensors. The muscles which assist in flexion of the neck are: longus capitis, longus colli, rectus capitis anterior, hyoideus and suprahyoid muscles, scalene medius and anticus and sternocleidomastoid (Foreman & Croft, 1988). The muscles which extend the neck are rectus capitis minor, rectus capitis major, obliquus capitis superior, obliquus capitis inferior, longissimus capitis, longissimus cervicis, semispinalis capitis, semispinalis cervicis and splenius capitis (Foreman & Croft, 1988).

Skeletal muscle consists of muscle fascicles which are composed of muscle fibres (Brooks, Fahey, & White, 1996). The fibres are made up of myofibrils which are composed of sarcomeres (Brooks et al., 1996). Sarcomeres consist of myofilaments and are the basic contractile units of skeletal muscle (Brooks et al., 1996). There are several connective tissue membranes surrounding the different sections of skeletal muscle and each has a function (Brooks et al., 1996). Each movement is possible due to the structure of skeletal muscle fibres and how they co-ordinate with the recruitment patterns of motor units (Brooks et al., 1996). Muscles are connected to joints by tendons, at the myotendinous junction. They allow the force generated by the muscle fibres to be transferred through the tendons to the bones to produce a movement (Brooks et al., 1996).

2.3 Skeletal Muscle and It's Adaptation

It was anticipated that the moderate +Gz the trainee pilots flew under would provide a stimulus for muscle strength and possible growth. According to Jones and Round (1990), high forces need to be applied before any new muscle growth can occur. However, it is still unclear whether it is high force that causes the change in strength or the recruitment of all the motor units to the training stimulus (Jones & Round, 1990).

Jones and Round (1990) suggested that there are three possible stimuli for muscle strength. These are hormonal stimuli, metabolic stimuli and mechanical factors. Mechanical factors appear to be the most probable stimuli for trainee pilots to see an increase in muscle strength. There are three main ways in which muscle strength might be affected by mechanical stress. Firstly, high force causing damage to sarcomeres, which provides a stimulus for repair and compensatory growth (Jones & Round, 1990). Also, mechanical stimulation can cause an increase in protein synthesis and degradation. It has been suggested that activity activates certain hormones in the body, which assist in increasing strength (Jones & Round, 1990). Lastly, connective tissue is a major part of muscle, and it is subject to stress because it provides the link between the force generating components and the tendons (Jones & Round, 1990). If an increase in the cervical muscle strength of the trainee pilots is found, the stimulus for this increase will most likely come from mechanical factors, in particular the loading (+Gz) the pilots undergo whilst executing flight manoeuvres.

An important aspect to this study is discovering whether or not the cervical muscles will naturally adapt to the load placed on them by the +Gz forces. According to Lieber (1992), skeletal muscle is one of the most adaptable (plastic) tissues in the body. Lieber (1992) suggested that there are five methods in which muscle adapts to increased use. These are adaptation to chronic electrical stimulation, adaptation to chronic stretch, adaptation to compensatory hypertrophy, adaptation to intermittent electrical stimulation, and adaptation to exercise and loading (Lieber, 1992). The most likely adaptation in the skeletal muscle for the RAAF trainee pilots is through exercise and loading as the +Gz forces are a form of loading.

In order for adaptation to occur a muscle's function must be stressed enough to overload the body (Brooks et al., 1996). If the stress is not sufficient adaptation to the muscle will not occur. However, if the stress becomes too great and cannot be tolerated, injury or over-training will occur (Brooks et al., 1996). Injury may be a factor in high performance pilots pulling +7Gz and above (Hamalainen et al., 1999), but not a factor for the RAAF trainee pilots who fly between +2-6Gz.

The principles to adaptation include overload, specificity, reversibility, and individual differences (Brooks et al., 1996). Overload occurs when muscles are forced to contract at tensions close to their maximum, then an increase in size and strength occurs. Specificity is found when the muscles that are being loaded are the muscles that adapt to the stress, and reversibility occurs when muscles adapt to an increase in stress by increasing their function (Brooks et al., 1996). However muscles can also decrease in strength and mass with disuse, immobilization or starvation (Brooks et al., 1996). The final principle to muscle adaptation is individual differences. Genetics play a role in the rate and amount of increased strength an individual gains over time (Brooks et al., 1996). It is not the sole determinant, a good training program can assist with development within a certain range.

Three of the principles to muscle adaptation will apply to the trainee pilots, these are overload, specificity and individual differences. The principles of overload and specificity will be seen in the trainee pilots if there is an increase in their cervical muscle strength. Overload will be established if the results obtained from the EMG data indicate that the cervical muscles of the pilots are being contracted to or above maximal voluntary contraction (MVC). Specificity will be shown if the cervical muscle region of the trainee pilots increases significantly compared to the control group, indicating that moderate +Gz loading increases the cervical region specifically.

2.4 Effects of +Gz on the Body

The effects of +Gz on the body vary depending on the person (G-tolerance) and the level of +Gz that they are exposed to. The effects of +Gz on the body begin to occur at +2Gz and by +3Gz it is impossible to raise oneself from a sitting position (Ernsting & King, 1988). Between +3-8Gz the movement of the unsupported limbs becomes increasingly more difficult, and upward movement of the upper limbs is impossible (Ernsting & King, 1988). Above +8Gz (without a helmet) and +4Gz (with a helmet) a pilot cannot raise their head once they have allowed their head to flex (Ernsting & King, 1988). The helmet has a mass of approximately 2kg and this has an effect on the positioning of the centre of gravity of the head relative to the atlanto-occipital junction and upper thoracic vertebrae. With this additional weight, forward flexion of the head under +Gz acceleration often occurs. It is the extreme forces that +Gz loading places on the body and especially the cervical region, which warrants the need for this study.

New aircraft are capable of sustaining +8-10Gz for up to 60 seconds but it is unknown whether a pilot's cervical neck muscle strength can adequately support these loads and prevent injuries from occurring (Royal-Australian-Air-Force, nd). The limiting factor in the aircraft is the pilot, as exposure to +4Gz for a prolonged period of time will eventually lead to a loss of consciousness (Royal-Australian-Air-Force, nd). Fatigue also becomes a limiting factor, with repeated exposure to air combat manoeuvring the pilot places large strains on their body for long periods of time, and the risk of injury increases the longer the time spent in the air (Royal-Australian-Air-Force, nd).

Twelve +Gz may be withstood by a pilot, but for no longer than two seconds, any longer and loss of consciousness without warning will occur. Warning symptoms such as greyout or blackout eventuate at a slower onset rate (Royal-Australian-Air-Force, nd). The prone position is the optimum position for +Gz tolerance, this however is not possible when flying tactical aircraft (Royal-Australian-Air-Force, nd). An F-16 aircraft has a seat which is reclined to about 30^0 (Royal-Australian-Air-Force, nd). These restrictions coupled with muscle and bone weaknesses make humans a limitation to high performance flying. This study will assist in bridging the gap between the limitations of pilots and the capabilities of the aircraft.

2.5 Muscular Strength of the Cervical Area of High Performance Pilots

There has been only one study published that has examined cervical muscle strength and muscle endurance in high performance pilots (Alricsson et al., 2001). The Alricsson et al. (2001) study researched muscular strength and endurance of the cervical spine of the Swedish Air Force jet pilots. Due to no differences being found between the pilots and the control group during the cervical spine extension endurance test, it was concluded that isometric endurance of the extensors was unlikely to be influenced by flying jets (Alricsson et al., 2001). A clear difference (10%) between the flexors and extensors of the cervical spine was found, however it was endurance of the flexors in pilots that was reduced and not in the control group (Alricsson et al., 2001).

Overall the pilots recorded higher cervical muscular strength than physically active people with different occupations (Alricsson et al., 2001). This may indicate that +Gz does have an effect on cervical muscle strength. Other limitations were that the pilots were not questioned about flying hours under high +Gz or outside (weight) training programs, both of which could have affected the cervical strength and muscle endurance of the pilots.

There does not appear to have been any longitudinal studies that have looked directly at the effect that +Gz forces have on cervical muscle strength, and whether the neck muscles adapt to withstand the forces experienced during flight by high performance pilots. Several studies suggest that in order to increase cervical muscle strength and avoid injury, it is necessary to use specific cervical exercises within a resistance program (Alricsson et al., 2001; Conley et al., 1997a, 1997b; Hamalainen et al., 1998).

There appears to have been no research to support the suggestion that a specific resistance program will assist in increasing the cervical muscle strength of pilots, and therefore decrease the incidence of neck injuries in high performance pilots. More specific information regarding cervical neck muscles, and the effect of +Gz loading on pilots will assist further research in answering the questions raised relating to resistance programs.

2.6 Range of Movement of the Cervical Spine and High Performance Pilots

There have been very few studies, which have looked directly at the range of movement of the cervical spine in high performance pilots. Alricsson et al. (2001) examined the differences in range of movement (ROM) in flexion-extension, rotation and lateral flexion of the neck between Swedish Air Force jet pilots and a control group. A decrease in the pilots' cervical spine rotation range was found and Alricsson et al. (2001) suggested that the decrease may have been caused by either shortening of the muscles or degenerative changes brought on by the high +Gz (+7Gz).

Other studies have compared the range of movement between age and gender related groups (Dvorak, Antinnes, Panjabi, Loustalot, & Bonomo, 1990) and patients with neck pain compared to healthy patients (Jordan et al., 1997). Dvorak et al. (1990) found that range of movement decreased as age increased, in particular in the 30-50 year age groups. Both genders exhibited a decrease in range of movement although women of the same age displayed less of a decrease in range of movement than men. However rotation of the C1-C2 segment was found to increase with age, and Dvorak et al. (1990) suggested this may be to compensate for the decreased motion in the lower segments of the cervical vertebrae.

Results from the Jordan et al. (1997) study found that range of movement was reduced in all female groups and reduced in a few of the male groups when comparing patients with neck pain to healthy patients. These results conflict each other in the area of gender but both studies agreed that as age increases the range of movement of the cervical spine decreases. The studies by Dvorak et al. (1990) and Jordan et al. (1997) do not relate to this study, as the subjects used were not high performance pilots.

A change in range of movement for the pilots would not be anticipated over this eight-month study. Range of movement was tested because it was felt that re-testing the pilots in the latter stages of their careers in high performance flying may exhibit decreases in the cervical spine, which would compare to the studies by Dvorak et al. (1990) and Jordan et al. (1997). According to Newman (1997) neck pain decreased the tactical performance of high performance pilots, especially during dog-fight manoeuvring where high ROM was needed.

This reduction in ROM during air combat manoeuvring may impair a pilot's performance and consequently have an effect on their career.

2.7 EMG and High Performance Pilots

To gain greater knowledge of the strain +Gz forces place on the cervical muscles of high performance pilots electromyography (EMG) can be used. "Electromyography is the measurement and study of the electrical activity that is associated with, and important for, the contraction of skeletal muscle" (Ross, 1993). Many studies have looked at the strength of cervical musculature using EMG (Choi & Vanderby, 2000; Conley et al., 1997a; Hamalainen & Vanharanta, 1992; Hamalainen et al., 1993; Harms-Ringdahl, Ekholm, Schuldt, Nemeth, & Arborelius, 1986; Jordan, Mehlsen, Bulow, Ostergaard, & Danneskiold-Samsoe, 1999; Oksa et al., 1996; Oksa et al., 1999; Phillips & Petrofsky, 1983a, 1983b; Schuldt & Harms-Ringdahl, 1988). However, very few of these studies have looked directly at the effect +Gz forces have on the cervical muscles (Hamalainen & Vanharanta, 1992; Oksa et al., 1996; Oksa et al., 1999).

Oksa et al. (1996) measured the mean and peak muscle strain of six fighter pilots during aerial combat manoeuvring exercises. Areas of the body measured were the thigh (rectus femoris), abdomen (rectus abdominus), back (erector spinae) and lateral neck (sternocleidomastoid) (Oksa et al., 1996). The mean and peak muscular strains for each muscle were calculated as a percentage of the pilot's maximal voluntary contraction (MVC) (Oksa et al., 1996). The results found from the Oksa et al. (1996) study was that the strain in the lateral neck was the highest and that the mean muscular strain of all areas was 5.2-19.8% MVC. The highest peak strain recorded was 257% MVC which was measured in the lateral neck (Oksa et al., 1996). This particular manoeuvre caused an injury to the lateral neck area and the flight was consequently discontinued (Oksa et al., 1996). Oksa et al. (1996) concluded that the demands placed on the neck and shoulder areas of fighter pilots are clearly higher than those of the average population, which also increases the pilots susceptibility to injury.

Oksa et al. (1999) also completed a study examining muscle fatigue caused by repeated aerial combat manoeuvring exercises. Six pilots performed one-to-one dog fight exercises three times in one day (Oksa et al., 1999). EMG data was measured from the abdomen (rectus abdominus L4-L5 height), back (erector spinae T 4-5 height), neck (erector spinae C4-5 height) and lateral neck (sternocleidomastoid) (Oksa et al., 1999). Oksa et al. (1999) found that the maximal muscle strength in the neck and lateral neck decreased the most (8-10%) between the first and last measurements. Mean muscular strain increased in all areas during the last flight, but only the neck and lateral neck exhibited significant increases (Oksa et al., 1999). Such findings may partially account for the high rate of neck injuries in pilots.

The study by Hamalainen and Vanharanta (1992) focused on average surface-integrated EMG (IEMG) measurements of the cervical erector spinae muscles compared to the pilot's MVC's. It was found that subjects used 55.8% of MVC during an extension of the head movement while flying under +4Gz (Hamalainen & Vanharanta, 1992). During this manoeuvre one pilot averaged

100% of MVC in the left cervical erector spinae muscle (Hamalainen & Vanharanta, 1992). When rotating the head (under +4Gz), 79.5% of MVC was found as the mean, and three subjects were measured at over 100% of MVC (Hamalainen & Vanharanta, 1992). Manoeuvres appear to influence the strain on the cervical muscles, only 15.8% of MVC was recorded when no manoeuvre was performed whilst pulling +4Gz (Hamalainen & Vanharanta, 1992). As +Gz increase so to does the demand on the cervical erector spinae muscles. Hamalainen and Vanharanta (1992) found a mean muscular strain of 37.9% of the MVC while pulling +7Gz, which shows an increase of 22.1% for the additional +3Gz pulled.

According to Oksa et al. (1999) and Hamalainen and Vanharanta (1992) factors that affected the neck area were weight of the helmet and positioning of the head. Oksa et al. (1999) found that poor posture (eg. "check six" position) and high G-loading increased the load on the cervical spine 21 times. Oksa et al. (1999) found it surprising that although the neck and shoulder area appear to be the most problematic for fighter pilots no previous research had been undertaken within this area. Two years later and still very few studies have been completed in the area of cervical muscle strength, relating the data to injury to fighter pilots (Alricsson et al., 2001).

CHAPTER THREE

3.0 METHODS AND PROCEDURES

3.1 Subjects

An eight-month longitudinal study design was employed to monitor the isometric cervical muscle strength response and range of movement of Royal Australian Air Force (RAAF) trainee pilots flying Pilatus PC-9, compared to an age-height-weight matched control group. The subject cohort initially consisted of thirteen male RAAF trainee pilots. The pilots were aged between 20 to 27 years, with an average age of 22.6 years. All pilots were stationed at the RAAF flight training school at Pearce, Western Australia. At the completion of the eight-month study, the attrition rate of the pilots was 23%. The final pilot cohort consisted of nine pilots, with an average age of 20 years.

Ten control subjects were recruited from the Aviation and Sports Science courses at Edith Cowan University. Controls were matched at baseline for gender, age, height and body weight. Exclusion criteria for entry were past neck injuries, current participation in a neck resistance training program, or flying >+2Gz. No subject was excluded during pre-testing based on these criteria.

The study protocol was approved by the Australian Defence Medical Ethics Committee (ADMEC) and Edith Cowan University Human Research Ethics

Committee. Written informed consent (Appendix A) was obtained from each pilot and control subject, prior to participation in the study.

3.2 RAAF Pilot Training

The pilot's course commenced with six weeks of ground school at Pearce Airbase in Western Australia (WA) and was subsequently followed by 25 weeks of basic flight training. Basic flight training incorporated general flying, instrument flying, navigational flying and formation flying. Due to mechanical problems in the aircraft the course was postponed by a month and during that time the pilots were grounded. The course was completed by May 15, which was four weeks later than initially planned. Due to scheduling and time commitments for the use of the MCU post-testing of the pilots occurred five weeks before the completion of training. The higher +Gz flight training was held during the last four weeks of course which meant testing did not include the higher +Gz of the course.

The majority of +Gz pulled by the pilots averaged between 1 to 4 +Gz during basic flight school, and each of these aerobatic manoeuvres generates a G-force (Table 1). All flight training was conducted in a Pilatus PC-9 aircraft (Figure 1) with the mean flight time in the PC-9 being approximately 1.25 hours per day, 4 days per week for the trainee pilots. The total flying time for the course therefore were 168 hours, with 143 hours being completed before post-testing.

Table 1

Gravitational Forces Generated During Basic Training Manoeuvres in a Pilatus PC-9

Flight Manoeuvre	G-Force (+Gz)
General Flying	
Loop	1.0 - 4.0
Barrel Roll	3.0
Vertical Roll	4.0
Cuban Eight	-1.0 - 4.0
Lazy Eight	4.0
Rolling manoeuvres	-1.0 - 3.0
Navigational Flying	1.5 - 2.0
Formation Flying	
Wingovers	2.5
Breakaways	3.0
General Flying manoeuvres in Formation	(up to) 4.0

Figure 1. Pilatus PC-9 Aircraft.

3.3 Data Collection Equipment

3.3.1 Multi-Cervical Unit

The multi-cervical rehabilitation unit (MCU) (Hanoun, Canada) has been used by the LifeCare Whiplash Centre of WA since June 1999. It is used mainly for the assessment and treatment of whiplash and cervical spine injuries, but may also be used as a resistance training device. The MCU outputs in pounds (lbs) the isometric strength of the muscles that control the neck as well as the range of motion, which is measured in degrees (LifeCare, nd).

The MCU was used to measure the isometric neck muscle strength and range of movement of the subjects using the Melbourne protocol (Appendix B). A retired F/A-18 pilot was consulted prior to testing to advise on a flight-specific testing protocol. This resulted in the addition of two extension 20^0 tests (in the neutral and left and right 25^0 rotation positions) in conjunction with the standard Melbourne test protocol. These two additional tests represent cervical muscle strength in positions more specific to pilots, such as the check six position (looking over your shoulder for an opponent). The incidence of injury when the head is off-centre is higher than that in a neutral position (Newman, 1997a). Therefore, it is important to assess whether the neck is weaker, stronger or the same when positioned in non-neutral postures. Measurements were taken at baseline (before flying began under moderate +Gz) and taken eight months later, five weeks prior to the completion of flight training, due to a mechanical problem with the aircraft earlier in the course.

3.3.2 EMG Equipment

To gain further knowledge as to which cervical muscles the RAAF trainee pilots use more frequently or at a higher rate, an electromyogram (EMG) device was used. EMG was obtained during a test flight using a Mega Electronics ME3000P (Mega Electronics Ltd., Finland), 8-channel device and processed using Megawin and a customised software program generated using LabVIEW (National Instruments, USA). Video footage was also acquired using a lipstick camera connected to a Sony 8mm digital camera.

A questionnaire (Appendix C) was completed by all of the subjects enquiring as to information on previous medical conditions/injuries suffered (in particular neck pain), regular physical activity completed, smoking status and a food chart to gauge calcium intake by the pilots (necessary for a study being completed in conjunction with this study). Full written instructions for the completion of the questionnaire were provided, accompanied by a verbal explanation. The trainee pilots also read and signed a consent form. The form outlined what was required of them throughout the study, and how the information on completion of the study would be used.

3.4 Data Collection Procedures

3.4.1 Multi-Cervical Unit

A qualified and experienced physiotherapist collected the MCU data from the LifeCare Whiplash Centre of WA. Correct protocol was maintained throughout testing which was vital for the reliability and validity of results.

Subjects were seated in an upright position in the MCU and any headwear or heavy jackets were removed. The subject was strapped in firmly with two belts crossing the chest and fastened at either side of the waist. This was to minimize any body movement other than the cervical area throughout testing. Correct posture was maintained throughout testing and if the subject's posture moved to an incorrect position, the subject was repositioned by the physiotherapist performing the test. This ensured that the cervical muscles were isolated throughout testing. Testing of a subject took approximately thirty minutes.

To perform the Range of Movement (ROM) procedure, the subject's head was held in the neutral position by four pads (Figure 2). Once in position the subject was instructed as to which direction movement should be made (Figures 3-5). A built-in voice message instructed the subject when to start each procedure and when to stop. After performing each ROM direction three times the head pads were removed. The subjects were instructed throughout testing to push or work maximally through either the ROM or strength areas of testing.

To execute the isometric strength testing procedure, subjects were told to press maximally with either the forehead or back of the head (depending on the test) against one pad for three seconds. When pushing against the pad with the forehead, the subjects were instructed to keep their chin into their chest and feel like they were pushing down and through the pad. This position isolated the spine and cervical muscles recording a more representative measurement. Once again they were instructed when to start and finish by the in-built voice message of the MCU. Each subject performed three tests for each procedure and an average was obtained from these measurements.

Seat height was adjusted according to the height of the subject and the test being performed. The physiotherapist positioned the subjects according to the test being executed, this enabled a more representative measurement and between-subject reliability. All ROM and strength testing of flexion required the pads or force pad to be placed immediately above the eyebrows of the subject. Strength testing in extension required the force pad to be sitting on top of the external occipital obturance at the posterior of the head, and strength testing lateral flexion saw the force plate positioned under the top of the ear and aligned with the subject's eyebrows. Before the commencement of testing, subjects were advised of the possibility of slight neck soreness the following day and neck stretches were recommended by the physiotherapist following the completion of testing.

Results were saved within the MCU software and printed immediately following the completion of each test. Calibration of the MCU occurred once a month using free weights to test for correct strength of the unit in pounds (lbs).

ROM TESTING

Figure 2. Range of Movement Neutral Position using Multi-Cervical Unit

Figure 3. Right Rotation Range of Movement

Figure 4. Lateral Flexion Range of Movement

Figure 5. Extension Range of Movement.

STRENGTH TESTING

Figure 6. Flexion Strength Testing in the Neutral Position

Figure 7. Flexion Strength Testing in Neutral Flexion and 25^0 Right Rotation

Figure 8. Extension Strength Testing in Neutral Position

Figure 9. Extension Strength Testing in Extension 20^0

Figure 10. Left Lateral Flexion Strength Testing in Neutral Position

3.4.2 EMG

To assess cervical muscle activation during flight, surface electrodes were used to record EMG activity of the muscles of one RAAF pilot during a test flight. The preparation of the subject involved shaving of hair at the electrode placement sites, then the skin was abraided with a fine scourer and cleaned using an alcohol swab. Four Ag-AgCl electrodes were placed on the muscle belly level with cervical (C) C4/5 for sternocleidomastoid, on the upper trapezius pars descendens, C2 level for erector spinae. The distance between inter-electrodes for each muscle was 20mm (Figure 11). EMG signals were processed through a Mega Electronics ME3000 EMG analyser at 1000Hz (raw signal) and the amplified signal was filtered using a low pass Butterworth digital filter with a cut-off frequency of 5Hz to produce a linear envelope. Data was processed in a generic LabVIEW (National Instruments) program, and further analysis of data occurred using Microsoft Excel version 97.

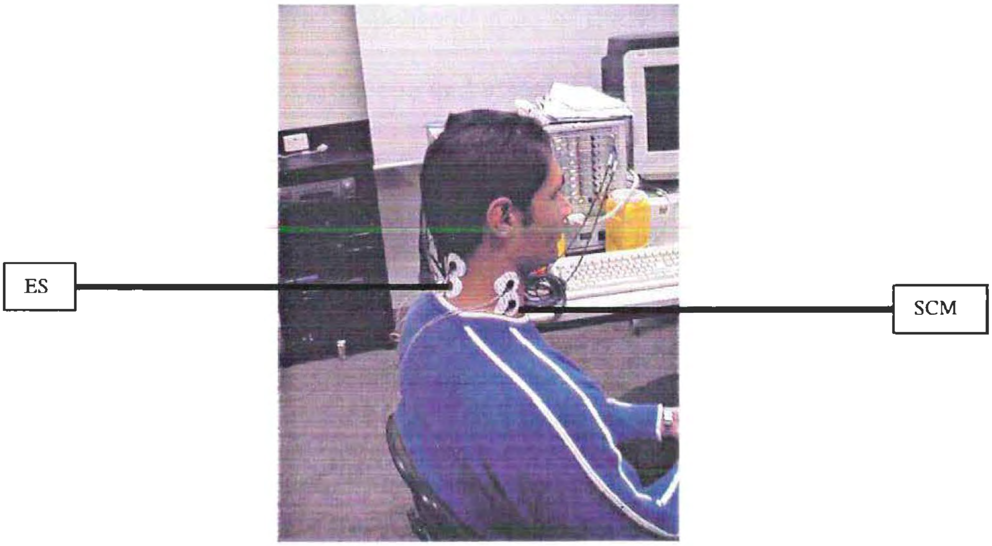

Figure 11. Surface Electrodes Placed on the Sternocleidomastoid (SCM) and Erector Spinae (ES) Muscles

The data logger was secured in the leg pocket of the subject's flight suit and the trigger was secured to the subject's arm. Wires connecting the electrodes to the data logger were placed inside the pilot's flight suit in order to minimize interference. Maximal voluntary contractions (MVC) measurements were gained prior to flight with the pilot sitting on a replica flight seat (strapped in as if ready for a flight) in the neutral position and then pushing against a force (outstretched hand) in the flexion, extension, extension lateral bending and twisting positions (right and left).

During MVC measurement the pilot was instructed how to operate the EMG data logger so that during flight it was activated only during flight manoeuvres. The flight consisted of a series of flight manoeuvres (turns, barrel rolls and loops) over a 30-minute period. Video footage of the pilot was also recorded to coincide with the EMG data collection. Video footage was obtained using a lipstick camera mounted in the cockpit facing the pilot, which was connected to a Sony 8mm digital camera. Synchronisation of the video with the data logger was made through both a verbal cue and visual interpretation of manoeuvres by the pilot. The video recorded a view of the pilot's head and the pilot explained the manoeuvres and levels of +Gz being flown during different phases of the flight. +Gz data from the PC-9 flight recorder was collected at 1Hz. Following the landing, all of the data was downloaded.

Video footage of manoeuvres which were similar to those executed by the trainee pilots were then synchronised with the EMG data by time (in seconds). The manoeuvres that have been used to compare muscle activation whilst under +Gz to the pilot's MVC were extension, right twist and left twist of the head.

whilst performing a left turn of the aircraft under +3Gz. Figure 12 exhibits the subject performing extension of the head while flying a manoeuvre under +3Gz. Figures 13 and 14 display a left and right twist of the head by the subject while executing a left and right turn under +3Gz respectively. The linear envelope of the EMG data was reduced to a two second portion of each movement and a maximal value recorded. The maximal value was then compared to the MVC data of the same head movement and a percentage of the MVC was calculated. To examine the pilot's cervical muscle endurance, an 88-second period of aerial manoeuvring whilst pulling +3Gz was analysed to find a mean IEMG for the pilot in the extension and flexion positions and a %MVC for the mean values was also calculated. The 88-second period was selected because the pilot executed a +3Gz left turn with a variety of extension and right and left twist head movements before flying the aircraft back to the level position with neutral head movements. The objective for using the EMG was to measure muscle activation during flight manoeuvres and head movements, so it was felt that the 88-second period assigned would give representative results of the flight tasks.

Figure 12. Extension of Head of RAAF Pilot while Performing a Manoeuvre Under +3Gz

Figure 13. RAAF Pilot Performing Left Twist while Executing a Left Turn Under +3Gz

Figure 14. RAAF Pilot Performing a Right Twist of Head while Executing a Right Turn Under +3Gz

3.4.3 Reliability of Multi-Cervical Unit

A reliability and validity study of the MCU has previously been examined (Greenwood, 2000; Greenwood & Nardis, 2000) and the MCU was found to be very sound for inter and intra-observer reliability of measurements using the Melbourne protocol. The validity of the equipment was also found to be sound, for more detailed information refer to the Greenwood (2000) preliminary report on the Multi-Cervical Unit. Further research at all four Whiplash Centres in Australia (Melbourne, Sydney, Perth and Adelaide) is continuing in order to further validate the MCU. Research into strength and ROM normative values for the MCU have been conducted and can been found in Appendix D.

The standard error of measurement (SEM) and the intra-class correlation (ICC) for the test-retest measurements of the Melbourne MCU protocol (not including additional reliability study) may be seen in Appendix E. The SEM measurements are low which indicates that the test-retest reliability for the measures using the MCU was good, and the ICC results also indicate sound correlation coefficients between therapists using the MCU. Thirty subjects were used during the reliability study of the MCU protocol (Greenwood & Nardis, 2000).

An additional reliability study was also completed on the isometric strength tests of neutral rotation extension 20^0 and rotation 25^0 extension 20^0. These two tests were not part of the reliability study conducted by Greenwood (2000), as they were recommended by the retired F/A-18 pilot specifically for this study. The additional reliability study consisted of ten male subjects who were tested on consecutive days by the same physiotherapist who tested the RAAF pilots and control subjects. An identical procedure to the pilots and controls was used although the initial test was completed in approximately ten minutes, as personal information needed to be input, and five minutes for the following days test. All of the reliability study participants were given full explanations of the procedure prior to testing and all consented.

Once the data for the reliability study was acquired, the information was calculated for technical error of measurement (TEM), percentage of TEM (%TEM) and intra-class correlation coefficient (ICC) (Dahlberg, 1940). A table of the raw data collected can be found in Appendix F. TEM was calculated using the following formula:

$$TEM = \sqrt{(\sum di^2 / 2n)}$$

The relative TEM was calculated using the formula:

$$\%TEM = [TEM / ((\overline{X_1} + \overline{X_2}))] \times 100$$

where; $\overline{X_1}$ and $\overline{X_2}$ are the means of the first and second series of measurements, respectively. The ICC's were calculated using the formula which was based upon one-way ANOVA calculations.

$$ICC = \frac{BetweenSubjectsMS - WithinSubjectsMS}{BetweenSubjectsMS + (k-1)WithinSubjectsMS}$$

where; MS is the mean square and k = number of measurements per subject (Dahlberg, 1940).

The results for the reliability study may be seen in Table 2. The ICC's show that the reliability of the additional tests was sound and the TEM's were similar to those found using the Melbourne Protocol in the initial reliability study (Appendix E).

Table 2

Technical Error of Measurement and Intra-class Correlation Coefficient's for Test-Retest using the Multi-Cervical Unit in the positions Neutral Rotation, 20^0 Extension and 25^0 Rotation, 20^0 Extension

Measurement	TEM	%TEM	ICC
0^0 Rot, 20^0 Ext	+/−3.35	12.44	0.901
25^0 Rot, 20^0 Ext Left	+/−2.55	10.51	0.930
25^0 Rot, 20^0 Ext Right	+/−2.65	10.94	0.920

Note. TEM is Technical Error of Measurement and is measured in pounds (lbs). Ten subjects were tested. Rot is abbreviated for Rotation, Ext for Extension. Left and Right is the direction of rotation (25^0) from the neutral position.

3.5 Data Analysis

Statistical procedures were carried out using SPSS for Windows (version 10.0). Comparisons between the pilots and control subjects for age, height and weight at baseline were made using an independent t-test. There were thirteen strength (dependent) variables obtained and six ROM (dependent) variables acquired during testing on the MCU. A correlation matrix was completed to give an indication of which movements were correlated and produced similar strength or ROM responses. A comparison in the difference between the pilots and control subjects for baseline and post-training (Figure 15), in neck strength for the isometric strength tests and ROM through flexion, extension, lateral flexion and rotation were made using an unpaired (independent) t-test (Norman & Streiner, 1999). Testing for normality and equal variances was completed and assumed for all variables. Due to these findings, a parametric test was used to analyse the data instead of non-parametric test, which would normally be used with such a small sample size. The sample size was small, but all of the available pilots did participate in the study. Statistical significance was accepted at $p < 0.05$.

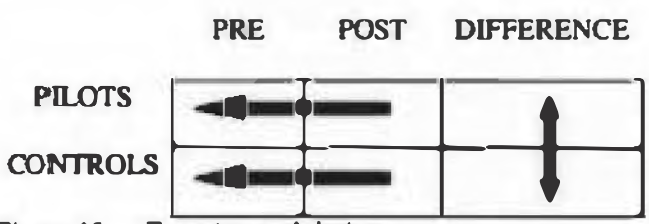

Figure 15. Experimental design

3.6 Limitations

3.6.1 Equipment of RAAF pilots. There was equipment failure (oxygen supply in planes) resulting in the course being postponed by a month. This may have had an effect on the final results as post testing occurred prior to the last four weeks of flight training where the highest +Gz flying of the course occurred. These additional four weeks of load on the cervical muscles may have shown a higher increase in strength compared to what was found in this study.

3.6.2 Small number of pilots within course may not be a true indication of strength changes over a larger population. All of the pilots from the course participated in the study, however it is an occupation which does not allow for large numbers to be trained at one time.

3.6.3 Pilots were aged between 20 years to 24 years, so these results may not necessarily apply to older populations.

3.6.4 EMG data was obtained from one pilot during one flight, resulting in a small sample size, which may not be a true indication of muscle activation for the majority of pilots

CHAPTER FOUR

4.0 RESULTS

4.1 Subjects

Table 3

Age, Height and Weight Values for the RAAF Trainee Pilot and Control Groups

	Pilots	SD	Controls	SD	p
No. Participants	9		10		
Age	22.0	1.1	22.6	4.4	0.2
Height	184.4	3.6	181.6	4.3	0.2
Weight	80.2	5.2	76.4	7.3	0.3

Presented in Table 3 are the physical characteristics of the RAAF trainee pilots and the control group. There were no significant differences found between age, height and weight of the RAAF trainee pilot and control groups.

4.2 Multi-Cervical Unit

After eight months of moderate +Gz flying, the pilots displayed a significantly greater increase in cervical muscle strength in flexion when compared to the control group (Table 4). There were no other significant differences found between the groups. However, there was a trend displayed by the pilots showing that their strength had increased in the areas of left and right lateral flexion. The control subjects exhibited no significant changes in any strength area over the eight-month study.

Table 4

Average Differences (Post - Pre) for Strength Values in the Neutral Position of Trainee Pilots and Control Subjects using the Multi-Cervical Unit

Test	Pilot mean	SD	Control mean	SD	t	p
Flexion	**5.4**	3.0	**1.7**	3.9	2.30	**0.034***
Extension	1.2	7.4	-0.4	6.3	0.51	0.616
Lateral Flexion Left	5.9	5.9	1.9	5.3	1.59	0.131
Lateral Flexion Right	6.4	6.6	2.3	5.1	1.53	0.144

Note. Averages are taken from three trials, and measured in pounds (lbs).

*Indicates a significant ($p < 0.05$) difference between the pilot and control groups.

There were no significant changes found for the rotation 25^0 and neutral flexion test between the pilots and controls (Table 5). Strength increases by the pilots in lateral flexion were found, but due to large standard deviations no significant change was recorded. The control group displayed no significant changes in rotation 25^0 and neutral flexion over the eight-month study.

Table 5

Average Differences (Post - Pre) for Strength Values in Rotation 25^0 and Neutral Flexion of Trainee Pilots and Control Subjects using the Multi-Cervical Unit

Test	Pilot mean	SD	Control mean	SD	t	p
Flexion Left	5.3	3.8	3.1	5.2	1.05	0.310
Flexion Right	6.6	5.4	4.9	5.7	0.62	0.540
Extension Left	0.9	7.0	1.6	5.6	-0.25	0.804
Extension Right	1.2	5.9	0.6	5.9	0.23	0.821
Lateral Flexion Left	5.7	7.7	1.7	4.0	1.46	0.163
Lateral Flexion Right	5.4	4.3	1.9	5.1	1.61	0.126

Note. Averages are taken from three trials, and measured in pounds (lbs).

Results exhibited during the neutral rotation, extension 20^0 and rotation 25^0, extension 20^0 tests showed that there were no significant changes between the pilot and control groups (Table 6). Neither group displayed an increase in strength for the extension 20^0 tests over the study.

Table 6

Average Differences (Post - Pre) for Strength Values in Neutral Rotation, Extension 20^0 and Rotation 25^0, Extension 20^0 of Trainee Pilots and Control Subjects using the Multi-Cervical Unit

Test	Pilot mean	SD	Control mean	SD	t	p
Rot 0^0 Ext 20^0						
Neutral	-2.4	8.2	-2.3	6.9	-0.02	0.984
Rot 25^0 Ext20^0						
Left	-2.3	7.5	-2.5	8.1	0.06	0.954
Right	-2.4	5.9	-2.1	7.2	-0.12	0.905

Note. Rot is an abbreviation for rotation. Ext is an abbreviation for extension. Averages are taken from three trials, and measured in pounds (lbs).

Presented in Table 7 are the comparisons between the baseline and post-testing strength results for the pilots, controls and LifeCare normative values using the MCU Melbourne protocol. The results show the pilots had above average neck strength in all of the positions tested. The control group exhibited below average or results at the lower end of the normative values for all of the strength positions.

Table 7

Comparison Between LifeCare Normative Values, the Pilot and Control Groups for Pre and Post-Strength Testing using the Multi-Cervical Unit – The Melbourne Protocol

Test	Pilots Pre	Post	Controls Pre	Post	Norms
Strength					
Flexion	24.1	29.5	18.8	20.8	20-25
Extension	40.2	41.5	25.8	25.9	25-35
L/Flexion	28.9	35.1	18.3	21	20-25

Range of Movement (ROM) in the pilots showed no significant change over the eight-months. These findings were in contrast to the controls who exhibited a significant decrease in flexion and an increase in left lateral flexion (Table 8). No other significant changes were found for either group during the study.

Table 4

Average Differences (Post - Pre) for Range of Movement (ROM) Values of Trainee Pilots and Control Subjects using the Multi-Cervical Unit

Test	Pilot mean	SD	Control mean	SD	t	p
Flexion	**-0.1**	4.9	**-10.9**	12.7	2.38	**0.030***
Extension	3.6	5.2	-0.9	5.9	1.74	0.100
Lateral Flexion Left	**2.0**	5.3	**8.6**	7.5	-2.17	**0.044***
Lateral Flexion Right	1.5	5.3	4.8	10.5	-0.85	0.408
Rotation Left	-1.4	3.7	1.4	9.3	-0.83	0.418
Rotation Right	1.4	3.4	-0.3	7.2	0.63	0.538

Note. Averages are taken from three trials and measured in degrees.
*Indicates a significant ($p<0.05$) difference between the pilot and control groups.

4.3 EMG

Figure 16 illustrates the extent to which both muscles were activated whilst manoeuvring under +3Gz. Exhibited are the activation levels above baseline for %MVC of the sternocleidomastoid and erector spinae for the three positions; extension (52.9% & 56.2% respectively), left twist (26.1% & 44.8% respectively) and right twist (97.8% & 35% respectively). The sternocleidomastoid appears to work very hard during right twist (97.8%), whereas the erector spinae is loaded more during extension (56.2%) and left twist (44.8%). The sternocleidomastoid is the major muscle involved in the flexion action and the erector spinae the extension movement. Therefore, these results indicate that when performing a left turn under +3Gz the sternocleidomastoid, has more of a flexed position during the right head twist and the erector spinae is activated more during extension and left twist head movements.

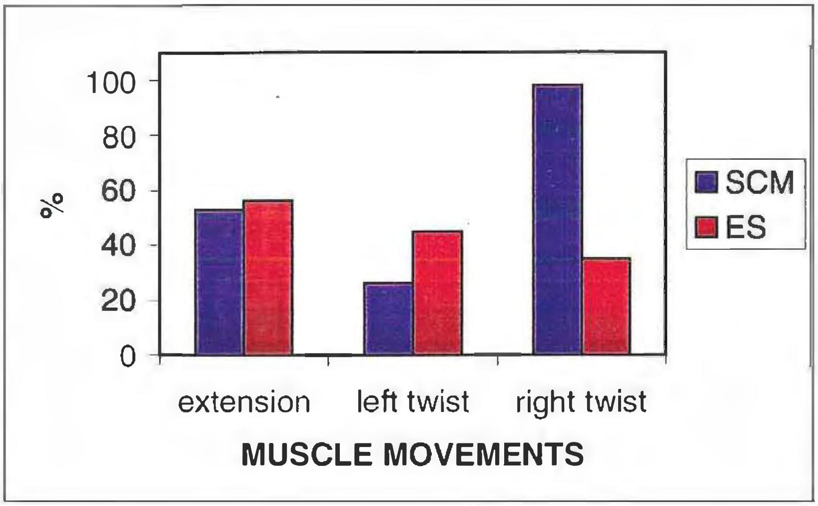

Figure 16. %MVC for sternocleidomastoid (SCM) and erector spinae (ES) muscles of a RAAF pilot executing a left turn while pulling +3Gz.

The mean flexion and extension measurements as well as MVC's for flexion and extension during the 88-second period were calculated to find a %MVC. This data is displayed in Table 9. During the flight the erector spinae muscles were activated to a much higher level (89.5%) than the sternocleidomastoid muscle (13%). This may indicate from Figure 16, that there were more extension and left twist movements than right twist movements during this section of flight, as the erector spinae (89.5%) was found to have higher %MVC than sternocleidomastoid (13%).

Table 9

Mean Flexion and Extension Measurements and Maximal Voluntary Contractions (MVC) Over an 88 Second Period of Aerial Combat Manoeuvring by a RAAF Pilot Flying a Pilatus PC-9 under +3Gz

Muscle	Mean (mV)	MVC (mV)	%MVC
Flexion SCM	22.00	168.654	**13.00**
Extension ES	66.72	74.55	**89.50**

Note. SCM is sternocleidomastoid muscle, ES is erector spinae muscle. Mean and MVC measurements in Millivolts (mV).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Multi-Cervical Unit - Strength

The main purpose of this study was to determine whether the moderate +Gz (+2-6Gz) generated during flight training stimulated an increase in isometric cervical muscle strength in pilots. An increase in muscle strength was found in flexion. This strength increase may have occurred due to the pilots continually working against +Gz to maintain a neutral head and trunk position during flying manoeuvres where the head and trunk were in an extended position. Examples of such flying manoeuvres in the extended position may include loops and barrel rolls, as well as during take off.

An explanation of this finding may be as follows. When completing daily tasks such as looking at a computer screen or reading a book, the head is in a forward flexed position (Chaffin & Andersson, 1991). To continually maintain this forward flexed position, activation of the neck extensors is required and minimal use of the flexors is needed (Chaffin & Andersson, 1991). Therefore, it can be deduced that in daily life the flexor group is rarely used, therefore it's potential for strength increases is greater than that of the extensor group. No other areas exhibited a significant strength increase. Such findings indicate that additional strength training may be required outside the aircraft to adequately prepare the pilots for flight, particularly fast jet flying.

However, there were increased strength trends displayed by the pilots throughout the strength tests, excluding extension 20^0 (Table 6). The trends towards increased strength suggest that some of the principles of adaptation did occur. The most likely principles utilised were overload and specificity. An overload would have been produced when the cervical muscles were forced to contract near maximum as shown by the EMG data. Specificity occurred because the cervical spine is highly loaded when executing flight manoeuvres under +Gz (Hamalainen & Vanharanta, 1992). These results indicate that muscle loading (+Gz) may have been the factor to increase cervical neck strength but not to a significant level. Further studies with higher +Gz forces may show more significant increases in cervical muscle strength.

Alricsson et al. (2001) examined muscle strength, endurance and range of movement of the cervical spine in a group of jet pilots compared to a control group. Results from the Alricsson et al. (2001) study found a strength increase in the neck flexors and extensors of the pilots. These findings were similar to this study, where the RAAF trainee pilots recorded an increase in flexion neck strength. This may indicate that a natural adaptation of the flexion cervical musculature occurs when flying under +Gz. Harms-Ringdahl et al. (1986) also suggested that when flying, the cervical spine flexors function as stabilisers compared to the extensors, which work actively. This requires greater amounts of work from the flexors (Harms-Ringdahl et al., 1986) and supports the findings in this study.

The results found using extension 20^0 were not significant and the pilot and control groups both decreased over the testing phase. An increase in strength of the extensors would not be expected, as it was not stressed during flight training. Aerial combat manoeuvring with dog-fighting and maximal use of the check six position commences in the fast-jet program. It is in response to the aerial combat manoeuvring that we would anticipate an increase in cervical musculature occurring in the off-centre positions.

During baseline testing the pilots exhibited above average neck strength compared to MCU normative values (Table 7). This indicates they had strong, healthy necks before entering into the high performance flight training program and increases in neck strength from baseline to post-testing may not have been as great due to their initial high neck strength values. The control group averaged below the normative values at baseline and at the lower end of the norms post-testing, suggesting they had low neck strength. There is no age limit for the norms making them a limitation when the average age of the subjects was 22 years and they may not have reached their peak level of strength.

It appears from the findings of this study, that the +Gz pulled by the RAAF trainee pilots did not significantly increase cervical muscle strength and thus may not adequately prepare the neck for higher +Gz flying and more intense flight manoeuvring (ie dog-fights). It was anticipated that greater strength changes would have occurred over the eight-month duration, however, due to mechanical problems with the aircraft earlier in the course, post-testing was completed prior to the highest +Gz flying of the course. This delay may have been a factor in the results exhibiting trends of increased strength and not the significant increases in cervical muscle strength expected. These findings support the notion of a pre-strengthening program, specific to the cervical neck muscles, confirming previous recommendations (Alricsson et al., 2001; Conley et al., 1997a, 1997b; Hamalainen et al., 1998).

5.2 Multi-Cervical Unit - Range of Movement

A second purpose of this study was to examine the effect +Gz had on the range of movement of the RAAF trainee pilots. The pilots displayed no change in range of movement (ROM). The control group exhibited the two significant changes found. These were a significant decrease in flexion and a significant increase in left lateral flexion. The decrease in flexion by the control group may have been caused by poor posture while studying, as the control group had finished their exams two days prior to testing. The findings for the pilot group support the hypothesis that ROM would not change during the eight-month duration of the study. The ROM area was tested due to expected changes occurring later in the pilot's careers and to see if any unexpected changes occurred during this study. The other ROM head positions produced no significant results. These results indicate that the pilots ROM was good and the moderate +Gz flown under by the trainee pilots did not have an effect on their ROM.

ROM is important when executing combat manoeuvres such as check-six, twists and rotations of the head. A previous study (Alricsson et al., 2001) found that high performance pilots displayed a decrease in cervical range of movement, which may have effected performance over a period of time. When executing the twists and rotations of the head the pilots are most susceptible to injury (Aho et al., 1990; Andersen, 1988; Knudson et al., 1988) and strength and ROM is important in these situations. This gives an important link between the two questions and shows the importance of ROM within this study.

The ROM results in this study can be compared to those by Alricsson et al. (2001) due to identical units of measurement being used in both studies. In the Alricsson et al. (2001) study however, the ROM flexion-extension movements were not measured separately, giving a total flexion-extension result. Lateral flexion and rotation were also measured over the full ranges, with no specific directions recorded. This is disappointing because there were differences found between left and right rotations and lateral flexions within the RAAF trainee pilot study using the MCU. Researchers should consider this when producing studies of this nature in the future.

To directly compare the two studies the ROM positions measured in this study have been calculated through each full range ie. flexion-extension, lateral flexion and rotation from the raw scores found in Appendix G. Table 10 compares the results in this study to Alricsson et al. (2001).

Table 10

Comparison of Range of Movement of Pilot and Control Groups to Alricsson et al. (2001)

Group	n	Flex-Ext	SD	Lat-Flex	SD	Rotation	SD
Alricsson							
Pilot	30	135.8	20	89.8	20.5	167.2	22.8
Control	33	142.6	17.6	97.5	15.7	185	21.6
Burton							
Pilot	9	136.1	15	105.4	15.2	175.1	11.7
Control	10	125.2	18.4	90.9	12.9	155.9	16.6

Note. Alricsson is abbreviated for Alricsson et al. (2001). Flex-Ext, Lat-Flex and Rotation measurements are all mean values, and measured in degrees.

Due to the large difference in sample size between the two studies it is difficult to suggest that they are an accurate measurement for all high performance pilots throughout the world. The RAAF trainee pilots recorded greater ROM compared to the pilots in the Alricsson et al. (2001) study. This would be expected, given the age differences between the pilot groups in the two studies. Dvorak et al. (1990) stated that mobility tends to decrease with age and the average age of the pilots in the Alricsson et al. (2001) study (30 years) was higher than all of the other groups. This may indicate why the pilot group in this study measured a higher ROM than the pilots in the Alricsson et al. (2001) study.

The Petren-Mallmin and Linder (1999) study also found that high performance pilots exhibited degenerative changes earlier than age-matched controls who had no military flying experience. These degenerative changes may be due to flying under high +Gz (Petren-Mallmin & Linder, 1999). This confirms the results found from the two studies because, unlike the pilots in the Alricsson et al. (2001) study, the RAAF trainee pilots did not fly under high +Gz, therefore these degenerative changes would not have been as likely to have occurred. It has been recommended that re-testing the range of movement of the current group of pilots should occur either in ten years time or at the end of their careers.

There has been no other research published which has examined the strength and ROM of high performance pilots and no study which looks specifically at trainee pilots and the effects +Gz have on the cervical spine. As was found with the strength side of the study, long-term research with these pilots may show changes in ROM (decreases) as +Gz increase and the load on the cervical muscles increase also.

5.3 EMG

When executing a +3Gz left turn it was found that the sternocleidomastoid (SCM) displayed a predominantly higher %MVC during a right twist than any other head movement. The SCM is the major muscle involved in flexion, and the large activation levels found during this study confirm the significant increase of strength exhibited for flexion by the pilots during testing of cervical muscle strength. Both ES and SCM displayed levels over 25%MVC activation for all head movements measured. These results provide some indication of the stresses placed on the cervical area during flight and the necessity for high performance pilots to have strong necks in order to cope with the loads.

Hamalainen and Vanharanta (1992) examined the effect of +Gz and head movements on cervical erector spinae muscle strain during high performance flying. Results from the Hamalainen and Vanharanta (1992) study indicated that as +Gz and head movements increased so to did the strain on the cervical area. It was concluded that if neck strength is insufficient to cope with the +Gz demands then acute neck injuries would be likely (Hamalainen & Vanharanta, 1992). The results found by Hamalainen and Vanharanta (1992) (55.8%) and in this study (56.2%) were very similar for ES. Hamalainen and Vanharanta (1992) researched the extension movement under +4Gz, compared to this study, which was performed under +3Gz. These results indicate the increases in +Gz did not effect the extension movement for this manoeuvre. These measurements also confirm the strength findings that the extensors do not work as actively during flight compared to the flexors.

Hamalainen and Vanharanta (1992) recorded a mean of 79.5% MVC (range of 28.2-189.7% MVC) for rotational head movements compared to this study 44.8% and 35% respectively for ES. The difference in +Gz was +4Gz and +3Gz respectively between the studies, indicating that as +Gz forces are increased the load on the body is also increased during rotational head movements. There were ten subjects measured in the Hamalainen and Vanharanta (1992) study compared to one pilot in this study. The greater number of subjects may give a more representative %MVC for the manoeuvre than using one pilot's results.

Oksa et al. (1996) studied muscle strain during aerial combat manoeuvring. Results from the Oksa et al. (1996) study found that the highest strain on the body during aerial manoeuvring was on the lateral neck (SCM). It is these peak strains, which present the highest risk of injury to the pilots (Oksa et al., 1996). Therefore, Oksa et al. (1996) concluded that maximal neck muscle strength was important when flying under high +Gz and recommended the cervical muscles be strengthened accordingly.

An endurance measurement was calculated over an 88-second period of aerial manoeuvring, the %MVC for flexion (SCM) was found to be low (13%), and extension (ES) high (89.5%). The mean flexion (SCM) %MVC (13%) can be compared to results found by Oksa et al. (1996) where a mean muscle strain for SCM during encounters was 18.7% MVC. This shows the overall loads placed on the SCM during longer periods of flight are minimal compared to the large peak strains, which occur during flight manoeuvres, indicating that maximal muscle strength is essential to combat injury occurring from high +Gz manoeuvring.

The mean muscle strain recorded by Oksa et al. (1996) for ES (17.8%) was very different to the results found for this study (89.5%). This may be due to the high amount of head movements performed in this study although the pilots in the Oksa et al. (1996) study were also executing aerial combat manoeuvring exercises. More research into this area is required to show more conclusive results for specific head movements during particular flight manoeuvres.

The Oksa et al. (1999) study examined muscle fatigue caused by repeated aerial combat manoeuvring exercises. It was concluded that the neck area exhibited the greatest levels of fatigue, which increased the risk for neck injuries. Oksa et al. (1999) recommended that the recovery of neck muscles from fatigue should receive special attention when performing multiple flights in one day. Therefore, both muscle strength and endurance are areas, which need to be focused on when strengthening the cervical area in high performance pilots.

5.4 Recommendations for Further Study

Due to the delay in training for the RAAF trainee pilots and post-testing using the MCU occurring before the higher +Gz flying in the course, there are areas which could be studied further to find more conclusive results. A significant strength increase was found for flexion in the pilots and increased trends seen in most areas, whether these trends become significant increases with higher +Gz loading is an area which could be studied further. The addition of the new test protocol, extension 20^0, requires further examination and this will occur if research using the MCU with the RAAF pilots continues. Further use of this test measurement may assist in understanding why a high proportion of cervical injuries occur in the check-six position. A decrease in the extension neck strength of the pilots was found during this study indicating that strengthening in this area needs to be a priority.

A similar study looking at the same pilots in the next phase of flight training, which would consist of flying under higher sustained +Gz, may find more significant increases in cervical muscle strength. With the results found in this study, it does suggest that the cervical muscles do not adequately adapt to the high stresses placed on the cervical area by +Gz. Therefore, it appears necessary for the specific neck strength weight-training program that many other studies (Alricsson et al., 2001; Conley et al., 1997a, 1997b; Hamalainen et al., 1998) have recommended, to be implemented.

Research investigating specific head positions during flight manoeuvring using EMG could also be examined more thoroughly. This area has not been researched previously and more muscle sites could be measured. To combine the two areas; strength and EMG, an EMG measurement could be recorded for each pilot when completing the MCU protocol testing. This would allow a comparison to be made between forces required in the air and forces output during testing on the MCU. However, the most important research to be undertaken within this area does appear to be the implementation of the specific neck-strengthening program.

5.5 Conclusion

This study examined the effect of moderate +Gz on the cervical muscle strength and range of movement of RAAF trainee pilots over an eight-month flight-training course. The first major finding of the study was that limited strength increases were found by the RAAF trainee pilots during flight training. Therefore, a specific neck strength training program, completed in conjunction with future flight training courses would be recommended. However, a significant increase was found in flexion. This may have been in response to the pilots continually working against +Gz to maintain a neutral head and trunk position during flying manoeuvres, where the head and trunk were in an extended position.

The second major finding was that the RAAF trainee pilots displayed above average neck strength compared to the normative values. This suggests the pilots entered flight training with strong, healthy necks. Due to their initial strength levels, a large increase between baseline and post-testing would not have been as likely.

The pilots exhibited good ROM throughout the study. As expected, there were no changes in ROM by the pilots, due to the short length of the course and to the level of +Gz being flown under being too low to see shortening occurring in the cervical muscles. ROM was measured for research over the pilot's careers, because changes in ROM would be more likely to occur over a number of years. As the +Gz and the pilot's age increase, a link may be found between ROM and cervical injuries. The results did show that during the flight training course ROM was maintained by the pilots. In contrast, the flexion ROM decreased and the left lateral flexion ROM increased in the controls.

The high recording of the stemocleidomastoid (muscle involved in flexion) found by the pilot pulling a +3Gz left tum and executing a right twist head movement confirmed the significant increase in flexion found during strength testing. The results from this area of the study assisted the neck strength section, as it was possible to measure the load placed on the stemocleidomastoid and erector spinae muscles during a similar flight to that of the flight training course. The endurance measurements showed the loads placed on the cervical muscles over a period of time and outlined how muscle endurance and maximal muscle strength are both essential to combat injuries which occur from high +Gz manoeuvring. The natural strength adaptation of the cervical muscles when flying under +Gz was not as high as expected. To cope with the loads placed on the cervical area during higher +Gz manoeuvring a specific neck strengthening program would be recommended for the pilots.

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APPENDIX A

INFORMED CONSENT FORM

EDITH COWAN
UNIVERSITY

Injury Prevention In RAAF Fighter Pilots: A Neck Strengthening Program for High Performance Pilots

INFORMED CONSENT FORM – RAAF PILOT GROUP

Thank-you for expressing interest in volunteering to take part in this study. The following information is presented in order to enable you to make an informed decision as to whether you wish to participate in the study. The information included outlines the procedures involved, together with the safeguards associated with participation in the study.

This study is being conducted with the aim of gaining understanding of the possibility of neck prevention and of bone health status of RAAF aircrew. Ultimately, by gaining such information, we hope to be able to enhance our knowledge in the aviation medical field, in addition to applying the knowledge to public and community health field.

Should you volunteer to participate in the study, you will be asked to undergo two neck strength and two bone mineral density scans over a 9 month period. Medical and nutritional questionnaires will also be administered at the commencement of the study. All data will remain confidential to the research team. The results of the tests will be made available to you at the end of the testing period.

I, ____________________________ give my consent to participate in the research titled: Injury Prevention in RAAF Fighter Pilots: A Neck Strengthening Program for High Performance Pilots, on the following basis:

- I acknowledge that the procedure has been explained to me, including the anticipated length of time it will take, the frequency with which the procedure will be performed and an indication of any discomfort which may be expected.
- I understand that my involvement in this study is voluntary and that I am free to withdraw from the study at any stage without penalty or detriment to my career.
- I am co-operating in this project on the condition that:
  - The information I provide is kept confidential
  - The information will be used only for this project
  - The results will be made available to me at my request and any published reports of this study will preserve my anonymity
  - I have been given a copy of the information sheet and this form, signed by me and by the principal researcher, Dr Fiona Naumann, to keep.

Signed (Subject) ______________________________ date __/ ____/ ____

Before me (Principal Researcher) ________________ date __/ ____/ ____

APPENDIX B

MCU – THE MELBOURNE PROTOCOL

The assessment protocol consisted of:

- Personal Details
    1. Name / DOB / Address / Phone Number

- Range of Movement (ROM) Testing (repeated 3 times)
    1. Flexion
    2. Extension
    3. Lateral Flexion (L / R)
    4. Rotation (L / R)

- Isometric Strength Testing (3sec isometric contraction/repeated 3 times)
    1. Flexion:
        1. Neutral ^{0} Rotation/Neutral Flexion
        2. 25^0 L Rotation / Neutral Flexion
        3. 25^0 R Rotation / Neutral Flexion
    2. Extension:
        1. Neutral ^{0} Rotation/Neutral Flexion
        2. 25^0 L Rotation / Neutral Extension
        3. 25^0 R Rotation / Neutral Extension
        4. Neutral ^{0} Rotation / 20^0 Extension
        5. 25^0 L Rotation / 20^0 Extension
        6. 25^0 R Rotation / 20^0 Extension
    3. Lateral Flexion:
        1. Left LF/Neutral ^{0} Rot/Neutral LF
        2. Right LF/Neutral ^{0} Rot/Neutral LF
        3. 25^0 L Rot/Neutral LF
        4. 25^0 R Rotation / Neutral

APPENDIX C

MEDICAL QUESTIONNAIRE

FIGHTER PILOT NECK STRENGTH STUDY

Confidential Medical Questionnaire

NAME:	________________	DATE:	_____/_____/_____
AGE:	__________ yrs	DATE OF BIRTH:	_____/_____/_____
HEIGHT:	__________ cm	WEIGHT:	_____/_____/_____

RAAF FIGHTER / RAAF / CONTROL (circle appropriate group)

1. Have you ever suffered or suffer from any of the following conditions?

Asthma:	Yes / No	Diabetes:	Yes / No
Renal Disease:	Yes /No	Heart Disease:	Yes / No

2. On an average basis, how many hours per week would you currently spend engaged in physical activity and exercise?

hrs/wk

Type of Exercise: ____________ ____________

____________ ____________

3. Are you a smoker? Yes / No

If YES, How many cigarettes per day do you smoke. __________per/day

4. Have you ever experienced any neck injury or neck pain in the past.

If YES, what was the nature of the injury or pain

____

____

5. Are you currently experiencing any neck pain?

Please circle:

No Pain   Very Mild Pain   Moderate Pain

Fairly Severe   Very Severe

6. Over the past week, how frequently did you consume the following foods? Please indicate the approximate number of standard serves per day or week. If you rarely have the item, just tick rarely or never.

FOOD	Standard Serve	Per Day	Per Week	Rarely or Never	Type
Milk Plain	1 glass (200ml)				
Milk Flavoured	1 glass (200ml)				
Milk On Cereal	½ Cup				
Milk In Tea/Coffee	30 ml				
Milkshake	Regular Size				
Thickshake	Regular Size				
Yoghurt	1 Tub (200g)				
Ice-Cream	1 Scoop (50g)				
Cream	1 Tablespoon				
Cheese Hard	1 slice (20g)				
Cheese Soft	1 slice (20g)				
Chocolate	1 bar (60g)				
Fish	1 med fillet 100g				
Meat	1 med steak 100g				
Chicken	Med fillet 100g				
Nuts	20g				
Fruit	1 average				
Vegetables	1 serve				
Cereals	1 serve				
Bread	1 slice 30g				

Thank-you

APPENDIX D

NORMATIVE VALUES FOR ISOMETRIC STRENGTH TESTING AND RANGE OF MOVEMENT USING THE MCU – THE MELBOURNE PROTOCOL

NORMATIVE VALUES FOR ISOMETRIC STRENGTH TESTING USING THE MULTI-CERVICAL UNIT - THE MELBOURNE PROTOCOL

FEMALES	
Flexion	12-17 lbs
Extension	20-30 lbs
Lateral Flexion	15-20 lbs
MALES	
Flexion	20-25 lbs
Extension	25-35 lbs
Lateral Flexion	20-25 lbs

No specific age was specified for these normative values

NORMATIVE VALUES FOR RANGE OF MOVEMENT USING THE MULTI-CERVICAL UNIT

Flexion	50^0
Extension	60^0
Lateral Flexion (Left)	45^0
Lateral Flexion (Right)	45^0
Left & Right Rotation	80^0

No specific age and gender was specified for the normative values

(LifeCare, nd)

APPENDIX E

RELIABILITY STUDY – STANDARD ERROR OF MEASUREMENT AND INTRA-CORRELATION COEFFICIENTS

Standard Error of Measurement for Test-Retest Measurements Using the Multi-Cervical Unit Melbourne Protocol

Measure	Therapist 1	Therapist 2	Therapist 3
ROM (degrees)			
Flexion	3.67	3.74	4.79
Extension	4.07	5.73	5.20
Lateral Flexion (Left)	4.34	4.08	3.71
Lateral Flexion (Right)	3.29	3.09	3.86
Isometric Strength (lbs)			
Flexion	1.75	1.54	1.67
Extension	3.97	3.43	3.19
Lateral Flexion (Left)	2.49	1.93	2.3
Lateral Flexion (Right)	1.9	2.39	2.04

Note. 30 subjects were tested (Greenwood & Nardis, 2000)

Intra-class Correlation Coefficients for the Test-Retest Reliability of Measurements for Each Therapist Using the Multi-Cervical Unit of the Melbourne Protocol

Measure	Therapist 1	Therapist 2	Therapist 3
ROM			
Flexion	0.859	0.806	0.725
Extension	0.742	0.531	0.624
Lateral Flexion (Left)	0.799	0.768	0.812
Lateral Flexion (Right)	0.842	0.861	0.829
Isometric Strength			
Flexion	0.857	0.873	0.862
Extension	0.654	0.789	0.677
Lateral Flexion (Left)	0.704	0.857	0.727
Lateral Flexion (Right)	0.879	0.837	0.826

Note. 30 subjects were tested (Greenwood & Nardis, 2000)

APPENDIX F

RELIABILITY STUDY DATA AND CALCULATIONS

neutral rotation 20 extension

											Means
	12.5	41.9	41.4	22.9	14.1	24.8	40.8	29.9	20	19.1	**26.74**
	16.6	38.6	36.6	22	12.9	37.1	37.2	32.5	18.9	18.8	**27.12**
Means	**14.55**	**40.25**	**39**	**22.45**	**13.5**	**30.95**	**39**	**31.2**	**19.45**	**18.95**	**26.93**
Total SS	208.2249	224.1009	209.3809	16.2409	164.6089	4.5369	192.3769	8.8209	48.0249	61.3089	1137.625
	106.7089	136.1889	93.5089	24.3049	196.8409	103.4289	105.4729	31.0249	64.4809	66.0969	928.057
											2065.682
Between SS	153.2644	177.4224	145.6849	20.0704	180.3649	16.1604	145.6849	18.2329	55.9504	63.6804	1953.032
Within SS	**112.65**										

One-Way ANOVA Table

	SS	df	MS
Between Subjects	1953.032	9	217.0036
Within Subjects	112.65	10	11.265
Total	2065.682	19	

ICC	0.9013
TEM	3.35
%TEM	12.44

25 rotation 20 extension (left)											**Means**
	11.9	40.8	35	21.5	13.5	29	37.3	29.7	16.6	15.4	**25.07**
	14.4	35.9	34.4	17.5	12.1	27.4	28.9	28.5	18.4	17.3	**23.48**
Means	**13.15**	**38.35**	**34.7**	**19.5**	**12.8**	**28.2**	**33.1**	**29.1**	**17.5**	**16.35**	**24.275**
Total SS	153.1406	273.0756	115.0256	7.700625	116.1006	22.32563	169.6506	29.43063	58.90563	78.76563	1024.121
	97.51563	135.1406	102.5156	45.90063	148.2306	9.765625	21.39063	17.85063	34.51563	48.65063	661.4763
											1685.598
Between SS	123.7656	198.1056	108.6806	22.80063	131.6756	15.40563	77.88062	23.28063	45.90063	62.80563	**1620.603**
Within SS	**64.995**										

One-Way ANOVA Table

	SS	**df**	**MS**
Between Subjects	1620.603	9	180.0669
Within Subjects	64.995	10	6.4995
Total	1685.598	19	

ICC	0.930325
TEM	2.55
%TEM	10.51

25 rotation 20 extension (right)

											Means
	13.2	34.3	35.2	21.2	14.1	31.4	40.9	28.9	16.3	16.1	**25.16**
	11.2	31.6	31	19.9	12	29.1	31.6	31.2	19.1	16	**23.27**
Means	**12.2**	**32.95**	**33.1**	**20.55**	**13.05**	**30.25**	**36.25**	**30.05**	**17.7**	**16.05**	**24.215**
Total SS	121.3302	101.7072	120.6702	9.090225	102.3132	51.62423	278.3892	21.94923	62.64723	65.85323	935.5743
	169.3902	54.53823	46.03623	18.61923	149.2062	23.86323	54.53823	48.79023	26.16323	67.48623	658.6313
											1594.206
Between SS	144.3602	76.30023	78.94323	13.43223	124.6572	36.42123	144.8412	34.04723	42.44523	66.66723	**1524.231**
Within SS	**69.975**										

One-Way ANOVA Table

	SS	df	MS
Between Subjects	1524.231	9	169.3589
Within Subjects	69.975	10	6.9975
Total	1594.206	19	

ICC	0.920644
TEM	2.65
%TEM	10.94

APPENDIX G

RAW DATA PILOT AND CONTROL GROUPS

RAAF PILOTS RESULTS USING MCU

AVERAGE AGE	22	HEIGHT			WEIGHT	
		GROUP AV	184.35	AVERAGE	Pre-test	80.19
				AVERAGE	Post-test	78.78

STRENGTH TEST — STRENGTH TESTING

Rotation 25 degrees Flexion 0 degrees

	Flex left av	Flex left max	Flex right av	Flex right max	Ext left av	Ex left max	Ext right av	Ext right max	Lat Flex left av	Lat Flex left max	Lat Flex right av	Lat Flex right max
PRE-TEST												
SUBJECT 1	32.1	34	33	36.8	51	51.8	51.6	51.7	46.7	50.9	44.8	46.6
SUBJECT 2	23.2	24.1	20.9	22.3	35	35.9	36.9	37.2	25.2	26.4	27.4	29
SUBJECT 3	15.9	16.5	14.7	15.6	32.9	36.6	28.1	28.5	25.7	27.4	23	24.3
SUBJECT 4	19.2	20.5	21.1	22.5	41.1	46	43.9	47.8	38	36.9	36.9	41.6
SUBJECT 5	30.4	31.7	26.1	27.8	51.4	51.8	50.3	51.5	40.3	44.3	41.3	43.8
SUBJECT 6	19.3	20.9	18.4	20.4	36.2	37.7	36.4	37.6	25.9	27.4	27	28.3
SUBJECT 7	28.7	30.2	30.1	30.6	51.8	51.8	51.3	51.8	36.4	42.4	41.5	44.8
SUBJECT 8	16.4	17.6	14.9	15.9	24.5	26.5	25.5	26.7	13.5	14.6	13.7	14.2
SUBJECT 9	29.7	30.9	29	30.6	38.1	41.3	38.6	39.9	38.3	41	39.9	44.8
GROUP MEAN	23.88	25.18	23.13	24.74	40.22	42.16	40.3	41.41	32.33	34.59	32.83	35.27
STD DEVIATION	6.42	6.61	6.7	7.22	9.52	8.87	9.72	9.84	10.61	11.39	10.5	11.59
POST-TEST												
SUBJECT 1	35.4	37	38.5	41	45.6	50.1	45.9	48.8	49.2	50.3	48.9	50.1
SUBJECT 2	33.2	36.8	34.7	37.9	38.1	39.1	38.4	42.2	28	30.5	29.3	29.6
SUBJECT 3	18.2	19.6	15.9	17.3	25.1	25.6	23.4	26.2	23.1	24.7	24.6	26
SUBJECT 4	22.2	23.2	23.9	25.2	40.1	43.8	41.7	46.3	38.4	39.9	40.1	41.7
SUBJECT 5	33.1	35.4	33.6	34.6	50.3	50.3	50	50.3	36.7	38.9	45	49.6
SUBJECT 6	25.5	28	20.3	21.4	34	38.9	40.5	42.7	42.6	44.5	41.5	44.9
SUBJECT 7	29.8	30.3	30.9	33.9	50.1	50.3	49	50.3	50.2	50.3	47.9	49.3
SUBJECT 8	28.8	30.3	29.5	31.2	37.1	40.2	36.1	38.1	28.4	30.8	24.1	26
SUBJECT 9	36.6	37.8	40	40.6	49.7	50.3	49	50.2	45.9	48.4	42.8	[illegible]
GROUP MEAN	29.21	30.82	29.7	31.46	41.12	43.18	41.56	43.9	36.06	39.81	38.24	40.56
STD DEVIATION	6.21	6.38	8.2	8.46	8.6	8.32	8.45	7.93	9.84	9.44	9.7	10.4
PRE-POST DIFF	5.33	5.64	6.57	6.71	0.9	1.02	1.26	2.49	5.72	5.22	5.41	5.29
PRE-POST DIFF	**10.06**	**10.06**	**12.43**	**11.94**	**1.11**	**1.2**	**1.53**	**2.92**	**6.13**	**7.02**	**7.01**	[illegible]

Rotation 0 degrees Flexion 0 degrees

	Flex av	Flex max	Ext av	Ext max	Lat Flex left av	Lat Flex left max	Lat Flex right av	Lat Flex right max
PRE-TEST								
SUBJECT 1	28.2	29.1	51.8	51.8	44.3	48.3	44	48.1
SUBJECT 2	26.8	27.4	33.8	34.3	21.8	22.9	21.6	22.4
SUBJECT 3	16.4	17.2	34.9	39.1	24.9	26.3	19	19.9
SUBJECT 4	16.4	17.3	37.8	38.8	28.1	30.1	32	35.1
SUBJECT 5	31.9	34.4	49	51.5	35.4	39.1	38.4	40.8
SUBJECT 6	23.1	23.7	37.2	40.4	22.9	24.2	21.1	22.5
SUBJECT 7	31	32.7	48.6	49.8	35.1	37.4	35.2	37.9
SUBJECT 8	13.7	14.6	23.3	26	15.6	17.8	15	15.6
SUBJECT 9	29	30.3	45.7	49	34.1	36.4	32.4	34.3
GROUP MEAN	24.06	25.19	40.23	42.28	29.13	31.39	28.74	30.73

STD DEVIATION	6.93	7.31	9.23	8.87	8.83	9.63	9.91	11.01
POST-TEST								
SUBJECT 1	33.3	38.5	48.5	50.3	50.3	50.3	47.8	48.8
SUBJECT 2	33	34	38.7	40	22.6	25.8	26.8	28.7
SUBJECT 3	21.1	23	25.5	25.6	22.4	23.3	21.2	21.7
SUBJECT 4	26.6	29	36.2	39.2	38.4	39.3	32	33.7
SUBJECT 5	33.5	36.5	50.3	50.3	40.5	40.7	43.3	45.8
SUBJECT 6	27.5	28.3	40	42.8	40.8	42.5	40.5	42.8
SUBJECT 7	36.6	37	44.8	48.9	38.8	39.6	35.5	36.3
SUBJECT 8	23.8	26.4	40	41.8	24.5	25.9	22.1	23.9
SUBJECT 9	31.1	32.4	50.3	50.3	39.8	44.2	47.4	49.3
GROUP MEAN	29.5	31.68	41.48	43.26	35.12	36.84	35.18	36.78
STD DEVIATION	4.97	5.31	8.06	8.08	9.74	9.49	10.31	10.53
PRE-POST DIFF	5.44	6.49	1.24	0.98	5.99	5.46	6.43	6.04
PRE-POST DIFF	10.17	11.41	1.52	1.14	9.32	8	10.06	8.96

Rotation 0 degrees Extension 20 degrees

	average	max
PRE-TEST		
SUBJECT 1	51.7	51.8
SUBJECT 2	36.8	40.1
SUBJECT 3	40.9	44
SUBJECT 4	50.7	51.8
SUBJECT 5	47.5	51.8
SUBJECT 6	45.8	47.6
SUBJECT 7	51.7	51.8
SUBJECT 8	25.9	27.9
SUBJECT 9	51.2	51.7
GROUP MEAN	44.69	46.5
STD DEVIATION	8.77	8.17
POST-TEST		
SUBJECT 1	50	50.2
SUBJECT 2	42.8	46.6
SUBJECT 3	23.5	23.9
SUBJECT 4	40.2	42.5
SUBJECT 5	46.5	50.3
SUBJECT 6	39.8	41.8
SUBJECT 7	49.4	50.3
SUBJECT 8	36	37.8
SUBJECT 9	50.3	50.3
GROUP MEAN	42.28	43.72
STD DEVIATION	8.78	8.77
PRE-POST DIFF	-2.41	-2.78

PRE-POST DIFF	**-2.77**	**-3.08**

	Rotation 25 degrees Extension 20 degrees			
	av left	max left	av right	max right
PRE-TEST				
SUBJECT 1	51.8	51.8	51.8	51.8
SUBJECT 2	34.4	36.8	33.8	34.1
SUBJECT 3	35.5	36.4	34.9	35.8
SUBJECT 4	49.8	51.2	49	51.5
SUBJECT 5	46.7	47.5	47.7	50.8
SUBJECT 6	50	51.5	51.3	51.8
SUBJECT 7	51.1	51.8	49.8	51.7
SUBJECT 8	26.4	27.5	25.9	26.1
SUBJECT 9	47.4	51.8	45.4	46.8
GROUP MEAN	43.66	45.12	43.29	44.49
STD DEVIATION	9.15	9.19	9.34	9.84
POST-TEST				
SUBJECT 1	50.3	50.3	49.5	50.3
SUBJECT 2	36.3	36.6	31.7	33.4
SUBJECT 3	21.4	22.4	24.7	25.6
SUBJECT 4	36	36.7	35.2	36.6
SUBJECT 5	50	50.3	49.2	50.3
SUBJECT 6	44.5	46.3	49.7	50.3
SUBJECT 7	50.1	50.3	49.5	50.3
SUBJECT 8	33.5	36.1	26.6	31.3
SUBJECT 9	50.1	50.3	49.4	50.3
GROUP MEAN	41.36	42.14	40.83	42.04
STD DEVIATION	10.2	9.81	10.59	10.19
PRE-POST DIFF	-2.3	-2.98	-2.46	-2.44
PRE-POST DIFF	**-2.71**	**-3.41**	**-2.82**	**-2.82**

RANGE OF MOVEMENT TESTING

	Flex av	Flex max	Ext av	Ext max	Lat Flex left av	Lat Flex left max	Lat Flex right av	Lat Flex right max	Left Rot av	Left Rot max	Right Rot av	Right Rot max
PRE-TEST												
SUBJECT 1	67.9	70.1	55.1	55.6	61	62.6	51.6	52.7	92.9	94.5	84.67	85.9
SUBJECT 2	80	80.1	52.5	52.7	54.1	56.3	52.83	55.2	92.4	95.4	85.03	87.2
SUBJECT 3	79.5	80.2	63.5	65.3	41.4	43.7	40.37	43.1	84.4	85.3	82.2	83.7
SUBJECT 4	66.7	70.8	42.7	43.1	45	47	35.83	37.1	83.2	87	73.83	75.5
SUBJECT 5	68.9	72.3	68.5	68.8	71.9	73.1	65.03	65.9	102.5	103.3	91.37	92.4
SUBJECT 6	76.5	77.4	56.6	57.2	58.3	60.4	52.03	53.2	87.1	88.4	82.13	84.1
SUBJECT 7	80.1	80.2	61.3	61.5	52.3	53.4	44.43	44.9	100	102.5	86.77	86.4
SUBJECT 8	70	71.3	69.5	70.3	51.9	55.3	51.93	53.9	89.9	90.9	[illegible]	93.5
SUBJECT 9	75.3	76.7	74.1	74.2	57.8	59.7	45.43	47.3	102	102.9	75.07	[illegible]
GROUP MEAN	73.91	75.46	60.42	60.97	54.86	56.83	48.83	50.37	92.71	94.47	82.38	83.92
STD DEVIATION	5.56	4.32	9.76	9.83	8.96	8.68	8.5	8.36	7.37	7.11	[illegible]	5.33

POST-TEST												
SUBJECT 1	76.2	77.8	57.4	58.1	58.2	59.5	51.07	51.5	94.5	96.4	86.57	86.9
SUBJECT 2	79.2	79.9	67.4	68.1	65.8	67.6	49.73	52.8	93.8	96.8	85.23	87.5
SUBJECT 3	77.8	78.5	64.8	66.6	48.6	51	50.27	52.2	85.1	86.1	89.33	90.8
SUBJECT 4	62.8	64.8	50.5	52.1	45.6	46	46.4	46	87.2	89.8	76.13	78.5
SUBJECT 5	74.1	75.6	69.3	70.4	74.1	75	59.8	61.3	100.9	103.4	92.1	93.7
SUBJECT 6	76.8	76.3	61.5	62.6	52.7	55.6	53.5	56.4	84.4	85.8	79.03	81.4
SUBJECT 7	79.7	80	58.1	58.7	53.8	56.8	47.27	50.5	92.8	94.5	82.4	84
SUBJECT 8	61.4	62.6	71.9	71.9	56.7	59.5	48.97	51.6	87.4	88	83.13	84.2
SUBJECT 9	76	75.6	75	75.4	56.5	56.8	46.67	47.9	96	97.6	79.93	81
GROUP MEAN	73.76	74.9	63.99	64.88	56.89	58.64	50.3	52.24	91.34	93.04	83.76	85.33
STD DEVIATION	6.64	6.53	7.83	7.55	8.67	8.54	4.32	4.49	5.6	5.96	5.1	4.89
PRE-POST DIFF	-0.13	-0.56	3.57	3.91	2.03	1.81	1.47	1.68	-1.37	-1.42	1.4	1.41
PRE-POST DIFF	**-0.08**	**-0.37**	**2.87**	**3.11**	**1.82**	**1.57**	**1.48**	**1.83**	**-0.74**	**-0.76**	**0.84**	**0.83**

CONTROLS RESULTS USING MCU

AVERAGE AGE	22.6	HEIGHT			WEIGHT	
		GROUPAV	181.58	AVERAGE	Pre-test	78.4

STRENGTH TESTING | STRENGTH TESTING

Rotation 25 degrees Flexion 0 degrees

	Flex left av	Flex left max	Flex right av	Flex right max	Ext left av	Ex left max	Ext right av	Ext right max	Lat Flex left av	Lat Flex left max	Lat Flex right av	Lat Flex right max
PRE-TEST												
SUBJECT 1	11.7	13 3	9	9 7	207	21.9	25 8	26.8	184	19 3	173	187
SUBJECT 2	14.4	18.2	11 9	12 3	22.7	28.1	19.9	216	231	24 3	31 1	339
SUBJECT 3	16	18.4	18 1	17	11 8	12.5	105	10 8	72	8	69	7 6
SUBJECT 4	27.3	28.8	22.4	24 6	28.7	31.8	30.4	319	21.7	22 1	184	212
SUBJECT 5	18 3	17	12 5	12 8	28 1	27.4	20 8	20 8	18	18 5	209	22
SUBJECT 6	23.2	24 4	21.3	21 8	295	33 1	32 5	332	205	233	238	241
SUBJECT 7	7 8	7.8	7 3	7 5	9 7	10 2	9 8	10 7	9 7	10 4	9	9 4
SUBJECT 8	11.7	13 3	9	9 7	20.7	21.9	25 8	288	18 4	193	173	18 7
SUBJECT 9	21 7	22.4	24 8	27.8	482	51 7	48.3	486	33 7	36 1	296	30 1
SUBJECT 10	9	9.8	10.2	11 5	17 1	17 8	17 5	17 8	14 6	16 4	21 4	24
GROUP MEAN	15.89	16.94	14.45	15.45	23.52	2542	24.09	249	1853	19.77	1957	2097
STD DEVIATION	642	8.67	8.31	6 98	10 88	11 9	11 4	1138	7 36	778	775	8 12
POST-TEST												
SUBJECT 1	21 7	23.5	237	25.8	252	26	249	26	207	219	198	232
SUBJECT 2	26.2	273	247	25 6	28.9	31 1	276	30 2	309	313	35 1	36 8
SUBJECT 3	122	12.4	12.4	13	153	16	154	161	101	102	132	137
SUBJECT 4	28 5	28.1	24	25 7	40 4	424	40 1	41	30 4	319	30 3	312
SUBJECT 5	16.1	18 8	17 8	18.2	18	19	17 7	18 8	17 7	18 5	23	24
SUBJECT 6	239	24 8	249	25 7	242	24 9	24	252	23 2	25 1	20 8	21
SUBJECT 7	7 8	8 1	8.8	7	11 1	127	123	13 8	9 3	9 4	93	96
SUBJECT 8	15	18 9	15 8	16 4	205	21 3	193	21 3	15 4	155	135	14 4
SUBJECT 9	30 5	31 7	32.2	34 1	503	50 3	50.3	503	32.2	34 3	33 3	36 8
SUBJECT 10	10 2	10.8	11 8	12.8	17 8	19 3	15 8	17 5	121	13 3	16 2	16 6
GROUP MEAN	18.88	20 02	19 41	20 43	2515	28 3	2472	28	20 2	21 14	21 45	22 71
STDDEVIATION	7 82	8 1 4	7 77	8.25	12 04	11 92	1203	11 7	8 74	9 23	8 93	959
PRE-POST DIFF	3.1	3 08	4 98	4.98	1 63	0 88	063	1 1	1 67	1 37	1 88	1 7 4
PRE-POST DIFF '	**8.89**	**8.33**	**14.65**	**13.88**	**3.35**	**1.7**	**1.29**	**2.16**	**4.31**	**3.35**	**4.98**	**3.98**

Rotation 0 degrees Flexion 0 degrees

	Flex av	Flex max	Ext av	Ext max	Lat Flex left av	Lat Flex left max	Lat Flex right av	Lat Flex right max
PRE-TEST								
SUBJECT 1	15 1	168	193	204	153	16 1	153	15 5
SUBJECT 2	17 5	197	205	22 2	242	273	264	27
SUBJECT 3	182	18	135	139	8 6	8 9	6 6	7 3
SUBJECT 4	299	30 1	37	39	195	20 9	19	20 1
SUBJECT 5	14 8	162	297	332	166	16 8	23	23 7
SUBJECT 6	26	277	292	31 1	238	24 1	219	22 3
SUBJECT 7	76	7 8	126	128	121	126	10 1	10 5
SUBJECT 8	15 1	188	193	204	153	16 1	153	15 5

SUBJECT 9	27.1	29.6	61.2	51.8	26.8	30.3	29.9	32
SUBJECT 10	11.2	12.2	20.2	22.2	15.3	17.6	16.3	17.7
GROUP MEAN	18.81	20.3	25.81	27.2	18.02	19.23	18.61	19.32
STD DEVIATION	7.26	7.42	12.43	12.73	6.04	6.99	7.56	7.9
POST-TEST								
SUBJECT 1	22.1	23	23.2	25	18.8	19.7	22.5	23.9
SUBJECT 2	25.8	27.6	22.1	24.2	28.7	30.7	32.5	34
SUBJECT 3	10.9	11.8	16.3	16.5	8.7	9	11.5	11.8
SUBJECT 4	32.5	33.4	47.7	49.7	31.8	35.7	29.8	30.7
SUBJECT 5	15.1	16.9	18.5	20	16.9	17.6	20.9	21.1
SUBJECT 6	27.4	28.9	21.2	21.8	21.1	23	20	21.3
SUBJECT 7	8.4	9.3	13.1	14.1	9.9	10.4	8.3	8.8
SUBJECT 8	14.9	16.3	21	22.3	13.3	14.1	12.8	13.3
SUBJECT 9	30.3	31.2	50.3	50.3	35.5	37.1	35.3	37.1
SUBJECT 10	10.4	11.1	15.5	16.3	11.5	12.4	13.6	14.8
GROUP MEAN	20.82	22.04	25.93	27.1	20.52	21.92	21.49	22.44
STD DEVIATION	8.78	8.79	13.46	13.44	9.81	10.51	9.6	10.03
PRE-POST DIFF	2.01	1.74	0.12	-0.1	2.5	2.69	2.88	3.12
PRE-POST DIFF '	**5.07**	**4.12**	**0.24**	**-0.18**	**6.49**	**6.53**	**7.18**	**7.48**

Rotation 0 degrees Extension 20 degrees

	average	max
PRE-TEST		
SUBJECT 1	42.1	43.5
SUBJECT 2	24.1	25.9
SUBJECT 3	13.7	14.2
SUBJECT 4	29.3	30.9
SUBJECT 5	27.2	28.9
SUBJECT 6	29.2	31.1
SUBJECT 7	14.7	15.9
SUBJECT 8	27.4	29.7
SUBJECT 9	50.8	51.7
SUBJECT 10	20	20.9
GROUP MEAN	28.72	30.2
STD DEVIATION	11.8	11.84
POST-TEST		
SUBJECT 1	22.4	24
SUBJECT 2	25.1	26.8
SUBJECT 3	20	21.6
SUBJECT 4	31.9	33.5
SUBJECT 5	23.5	23.7
SUBJECT 6	24.8	25.9
SUBJECT 7	14.6	15.7

SUBJECT 8	23.5	24.6
SUBJECT 9	50.3	50.3
SUBJECT 10	19	19.3
GROUP MEAN	26.23	27.34
STD DEVIATION	10.11	9.8
PRE-POST DIFF	-2.49	-2.88
PRE-POST DIFF *	**-4.53**	**-4.98**

Rotation 25 degrees Extension 20 degrees

	av left	max left	a v right	max right
PRE-TEST				
SUBJECT 1	44.6	45.8	40	41.2
SUBJECT 2	25.1	27.4	27	27.1
SUBJECT 3	12.9	14.4	10.8	11.2
SUBJECT 4	30.1	32	30.4	31.6
SUBJECT 5	24.6	25.7	26.5	27.8
SUBJECT 6	32.3	35.9	31	34.9
SUBJECT 7	12.3	12.6	14.3	16
SUBJECT 8	25.2	26.3	26	27
SUBJECT 9	46.3	49.3	46.4	51.4
SUBJECT 10	20.3	23.4	19.4	21.2
GROUP MEAN	28.16	29.93	28.04	29.69
STD DEVIATION	11.91	12.48	11.11	12.3
POST-TEST				
SUBJECT 1	23.5	25.8	24.9	25.9
SUBJECT 2	28.5	28.6	29.3	32
SUBJECT 3	17.9	18	14.9	15.6
SUBJECT 4	33.9	35.3	38.6	43
SUBJECT 5	20.5	21.9	22.9	23.9
SUBJECT 6	23.1	25.7	19.8	20.3
SUBJECT 7	13.6	14.2	14.4	15.4
SUBJECT 8	21.1	23.3	20.7	21.1
SUBJECT 9	50.3	50.3	49.5	50.3
SUBJECT 10	16.2	17.1	15.9	16.3
GROUP MEAN	25.82	27.01	26.11	27.5
STD DEVIATION	10.88	10.62	11.49	12.13
PRE-POST DIFF	-2.33	-2.92	-1.93	-2.19
PRE-POST DIFF *	**-4.32**	**-5.13**	**-3.57**	**-3.83**

RANGE OF MOVEMENT TESTING

	Flex av	Flex max	Ext av	Ext max	Lat Flex left av	Lat Flex left max	Lat Flex right av	Lat Flex right max	Left Rot av	Left Rot max	Right Rot av	Right Rot max
PRE-TEST												
SUBJECT 1	79 9	80	52	52 2	41 3	44.2	4267	45 8	84 2	85 1	8337	84 5
SUBJECT 2	59 1	59 8	61.1	62 2	42.7	43	3543	37 7	77 3	80 1	75	78 4
SUBJECT 3	68 3	68.3	49 4	50 6	49.4	53	38 8	41 5	77 1	77 3	6963	71 5
SUBJECT 4	79 3	80.2	83 4	63 9	43.4	44 8	40 6	41 2	97 8	1005	86 8	89 3
SUBJECT 5	74 9	77 3	64	68 2	50.6	51.5	5143	53	79 2	80 9	7727	78 [illegible]
SUBJECT 6	79 1	79 3	55.4	65.7	39 8	42 7	3137	32 4	75 1	78 2	83 2	85 5
SUBJECT 7	68	68.4	63	83 9	46.4	47 3	38.23	40 1	53 3	56.2	63 73	66 8
SUBJECT 8	79 9	80	52	52 2	41.3	44.2	4267	45 8	84 2	85 1	8337	84 5
SUBJECT 9	76 4	78.5	82.9	63.2	46.9	47 4	39 77	41	81	83 6	6757	69 3
SUBJECT 10	80 1	80 5	60 4	51.4	35.4	37 2	39 9	42 9	81 5	87 6	70 73	73 1
GROUP MEAN	73.66	74.64	58.13	58 9	44 64	46.46	40 11	42.06	78 8	80 78	76 7	7866
STD DEVIATION	7 47	7,34	5 68	6.14	3 83	3.69	5 54	5 77	11 69	11 5	8 15	7 97
POST-TEST												
SUBJECT 1	38 7	40.2	49 1	52.1	46.5	49 8	43 9	44 5	75 4	76 9	7303	75 6
SUBJECT 2	54.3	55	64.1	65.3	51.3	52 4	46 6	48 5	73 5	78	71 67	77 6
SUBJECT 3	55.6	57 8	41 1	43 3	49 3	51 7	32	34 4	73	77 7	6783	68 2
SUBJECT 4	79 1	79 1	70 4	71 3	51.7	53 4	4883	50 1	94 5	96	85 7	87 8
SUBJECT 5	81.9	82 6	83 4	64	49	53 4	34 8	36	77 7	79 8	79 73	81 4
SUBJECT 6	58 5	60 1	54.5	57 6	43.8	45 8	34 3	34 6	75 3	76 5	80	81 9
SUBJECT 7	59 1	60 5	63	66 5	54 8	57 7	43 8	44 7	77 2	79 2	71 67	73 1
SUBJECT 8	79 5	79 7	45 2	46.7	64.5	67	5463	55	82 2	83 2	7803	76 6
SUBJECT 9	76 8	76	54.4	54 8	62 5	63 1	6073	61 7	69 6	91 1	82 73	84 2
SUBJECT 10	72.8	75.5	59 1	60 4	49 4	50 5	4897	49 2	86 1	87 8	70	71 7
GROUP MEAN	62.37	63.67	56.13	57.98	52 8	5492	44 4	45 5	7982	8227	7649	7849
STD DEVIATION	13.66	13.18	9.8	9 54	6 94	6 63	9.65	9.47	7 54	6 77	5 92	5 99
PRE-POST DIFF	-11.29	-10.98	-2	-0 94	7 98	8 47	4 29	3 44	1 02	1 49	-0 22	-0 17
PRE-POST DIFF	-8.3	-7.94	-1.75	-0.81	8.16	8.35	5.08	3.93	0.64	0.91	-0.14	-0.11