ROOPE SOVELIUS

Cervical Loading Analysis of Fighter Pilots

Studies on cumulative loading, contributing factors and interventions

■

ACADEMIC DISSERTATION
To be presented, with the permission of
the Board of the School of Medicine of the University of Tampere,
for public discussion in the Small Auditorium of Building M,
Pirkanmaa Hospital District, Teiskontie 35,
Tampere, on February 21st, 2014, at 12 o'clock.

UNIVERSITY OF TAMPERE

ROOPE SOVELIUS

Cervical Loading Analysis of Fighter Pilots

Studies on cumulative loading, contributing factors and interventions

Acta Universitatis Tamperensis 1906
Tampere University Press
Tampere 2014

UNIVERSITY
OF TAMPERE

ACADEMIC DISSERTATION
University of Tampere, School of Medicine
Finnish Air Force, Training Air Wing, Kauhava
Centre of Military Medicine
Institute of Occupational Health, Oulu
Finland

Supervised by
Professor Markku Järvinen
University of Tampere
Finland
Docent Juha Oksa
University of Jyväskylä
Finland

Reviewed by
Docent Markku Kankaanpää
University of Tampere
Finland
Professor Heikki Kyröläinen
University of Jyväskylä
Finland

Cover design by
Mikko Reinikka

Acta Universitatis Tamperensis 1906
ISBN 978-951-44-9376-8 (print)
ISSN-L 1455-1616
ISSN 1455-1616

Acta Electronica Universitatis Tamperensis 1390
ISBN 978-951-44-9377-5 (pdf)
ISSN 1456-954X
http://tampub.uta.fi

Suomen Yliopistopaino Oy – Juvenes Print
Tampere 2014

To Those Magnificent Men In Their Flying Machines.

They go up, tiddly, up, up.
They go down, tiddly, down, down.
They enchant all the ladies and steel all the scenes.
With their up, tiddly, up, up.
And they're down, tiddly, down, down.
Up! Down! Flying around.
Looping the loop and defying the ground.
They're all, frightfully keen.
Those magnificent men in their flying machines.
They can fly upside down with their feet in the air.
They don't think of danger. They really don't care.
Newton would think he had made a mistake.
To see those young men and the chances they take.
-Ron Goodwin

Contents

List of Original Communications

I Sovelius R, Salonen O, Lamminen A, Huhtala H, Hämäläinen O. Spinal MRI in fighter pilots and controls: a 13-year longitudinal study. Aviat Space Environ Med. 2008 Jul; 79(7):685-8.

II Sovelius R, Oksa J, Rintala H, Huhtala H, Siitonen S. Ambient temperature and neck EMG with +Gz loading on a trampoline. Aviat Space Environ Med. 2006 Jun; 77(6):574-8.

III Sovelius R, Oksa J, Rintala H, Huhtala H, Siitonen S. Neck muscle strain when wearing helmet and NVG during acceleration on a trampoline. Aviat Space Environ Med. 2008 Feb; 79(2):112-6.

IV Sovelius R, Oksa J, Rintala H, Siitonen S. Neck and back muscle loading in pilots flying high G(z) sorties with and without lumbar support. Aviat Space Environ Med. 2008 Jun; 79(6):616.9.

V Sovelius R, Oksa J, Rintala H, Huhtala H, Ylinen J, Siitonen S. Trampoline exercise vs. strength training to reduce neck strain in fighter pilots. Aviat Space Environ Med. 2006 Jan; 77(1):20-5.

Abbreviations

AFA	Air Force Academy
AGSM	Anti-G straining maneuver
BMI	Body mass index
C	Cervical
CES	Cervical erector spinae
CG	Centre of gravity
CI	Confidence interval
CLT	Cervical loading test
CSF	Cerebrospinal fluid
CT	Computer tomography
EMG	Electromyography
FINAF	Finnish Air Force
G-LOC	G-induced loss of consciousness
Gx	Frontal direction of inertial force
Gy	Lateral direction of inertial force
Gz	Vertical direction of inertial force
HIZ	High intensity zone
HMD	Helmet-mounted device(s)
INSMS	Isometric neck strength measurement system
L	Lumbar
LES	Lumbar erector spinae
MCU	Multi cervical unit
MRI	Magnetic resonance imaging
MVC	Maximal voluntary contraction
NATO	North Atlantic Treaty Organisation
NVG	Night vision goggles
R^2	Coefficient of determination
RAF	Royal Air Force
ROM	Range of movement
S	Sacral
SCM	Sternocleidomastoideus
SD	Standard deviation
STG	Strength training group
TES	Thoracic erector spinae
Th	Thoracic
TRA	Trapezius
TTG	Trampoline training group
VAS	Visual analogue scale

Abstract

The aim of the studies presented in this dissertation was to study the degenerative changes in the cervical spine due to high Gz exposure; some suggested contributing factors on the neck muscle strain under Gz; and effects of certain countermeasures in reduction of strain under Gz.

The subjects were volunteer cadets undergoing training in the Air Force Academy (AFA) of Finland (Studies II, III, and V) and subsequently followed-up during their later career (Study I), and AFA instructor pilots (Study IV). Experimental measures included cervical and lumbar magnetic resonance imaging (MRI) (Study I) and electromyography (EMG) for muscular electrical activity (Studies II-V) and the strength of the cervical flexor, extensor and rotator muscles. In addition to strength measurements and test flights, loads on the neck/shoulder muscles were simulated with a cervical loading test (CLT) (Study V). Skin temperatures were measured with a surface thermometer (Study II), and trampoline was used to simulate G-forces (Studies II-III) and as a training device (Study V). A six-week training consisted of strength training and trampoline exercises, for which purposes two training groups were formed.

All changes detected in the cervical spine during the follow-up were minor in both groups. Even though there were no significant differences between the groups, but changes in the pilot group seemed to concentrate in the lower cervical spine, i.e., C5-6 and C6-7, while degenerative changes in the control group were scattered more evenly. Both cold exposure and the extra mass of the helmet increased cervical muscle activity (EMG) under Gz. A regression model showed the increase of 2.6 % in muscle strain for every drop of one centigrade in skin temperature over the sternocleidomastoid muscles (SCM) during cold exposure. The results showed that the higher mass of the helmet had a more significant effect on cervical muscle loading than night vision goggles (NVG), which appeared to affect essentially those muscles that are inherently subjected to the highest loadings, i.e., SCM and cervical erector spinae (CES). There were indications of a tendency towards a lower muscle strain when a lumbar support was worn. Muscle activity (EMG) decreased in all measured erector spinae muscles in the cervical, thoracic, and lumbar regions; but these changes were not statistically significant. Training intervention improved the maximal force production in both groups. Training reduced in-flight muscle strain (%MVC) in both groups most significantly in cervical muscles and in the SCM in particular. CLT measurements yielded similar results. The positive effects of training period, i.e. decreased muscular loading, sustained in cervical area in both training groups (STG and TTG). No statistically significant differences between the groups were discovered.

In conclusion, high Gz exposures during over 1200 flight hours caused no significant radiological changes n the spinal column. Both cold exposure and the extra mass of helmet system increased cervical muscle activity (EMG) under Gz. It was hypothesised that Gz induced muscle strain could be reduced by improving the sitting posture with a lumbar support and/or by improving muscular capacity and performance through training. These two means seem to reduce muscle strain to some extent.

1 Introduction

Fighter pilots' neck pain and premature cervical degeneration have been an aeromedical topic as well as concern among pilots since modern high performance fighters have been used. A systematic study program was launched in Finnish Air Force in the early 1990's, including epidemiological surveys, clinical measurements, muscular responses and MRI case studies (Hämäläinen 1993a). These studies documented acute in-flight neck pain and addressed the high muscular strain during high Gz forces. They also showed that frequent exposure to high Gz forces could lead to premature cervical disk degeneration. NATO Research and Technology Organization later issued recommendations for the prevention of neck injuries to be implemented in pilot selection, physical conditioning programs as well as improved design for life-support equipment (Burton 1999). However, there is still a lack of documentation on evidence based effective countermeasures to help pilots better to withstand Gz loading. There is also a lack of controlled longitudinal studies to present the suggested fighter pilots' occupational premature spinal degeneration.

The problem, therefore remains extant present and unsolved.

The level and frequency of peak strain periods mean that fighter pilots' muscular strength endurance, especially in the neck and shoulder area, is subjected to demands clearly higher than among the general population (Oksa et al. 1996). It has been presented that repeated high-Gz flight sorties cause muscle fatigue and maximal voluntary contractions decreases in muscles, and particularly in neck region (Oksa et al. 1999). In addition, a modern helmet is more than a protective piece of equipment; it serves as a mounting platform for devices that enhance the pilot's performance. Night vision goggles (NVG), sighting systems and other ancillary items, increase load on the cervical area contrary to recommendations, which in turn increase the cervical loading in a high Gz environment.

Fighter missions are increasingly longer in duration. They may involve spending hours strapped in on quick reaction alert or extended sorties with air refuelling. This in turn may decrease neuromuscular motor control and blood flow in the muscles and lead to reduced muscular performance.

Since the risk of cervical injury or degeneration will be a pilot's constant companion throughout his/her career, the preventive strategies should be applied from the pilot selection and continuing throughout, and beyond, a pilot's career. While flight safety is jeopardized, it may cause further reimbursement after human symptoms, and claims for financial compensation may be raised after physical symptoms have been taken care of. Besides these human consequences, pilot's grounding drain of squadrons' human resources and operational capability. Since training a pilot costs millions of euros, even short duration grounding will be excessively costly and should be prevented by all available means.

2 The review of the literature

2.1 The biomechanics of the cervical spine and some applications in a high Gz environment

2.1.1 The magnitude of acceleration forces in-flights

The pilots of high performance fighters are frequently exposed to high headward accelerations, in which the direction of the resultant inertial force is from head to the feet (Figure 1). This inertial force is commonly called Gz force, in which the number of G represents the multiple of the Earth's gravitational force. In human body, Gz forces cause profound effects on mobility, vision, pulmonary functions and the level of consciousness. This study focuses on its effects on musculoskeletal loads, the mobility of the cervical spine and strain imposed on the adjacent muscles.

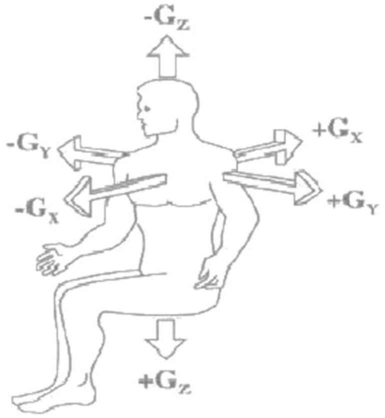


Figure 1 The directions of inertial forces and the standard terminology: Gx refers to the frontal, Gy to the lateral, and Gz to the vertical direction.

Air combat engagements with modern fighters consist of multiple, frequently repetitive excursions to high +Gz levels. Peak levels usually range from +7 to +9 Gz, and there are dozens of excursions above +2 Gz. Approximately 20% of the sortie time is spent with Gz loading above +2Gz (Newman and Callister 1999).

Australian studies have demonstrated that Gz-induced load during a one-year period of flight training in PC-9 turboprop, had an osteogenic effect on bone. Pilots' bone responses were determined to be site specific, and that positive effects on bone mineral density were found in the cervical and thoracic spine.

However, no significant changes in bone mineral quantity were observed in the lumbar spine, arms or legs. (Naumann et al. 2001; Naumann et al. 2004)

Mean muscle activity (EMG) is doubled when Gz rises from +4 Gz to +7 Gz (Hämäläinen 1993b). In the neck flexors especially, and to some extent in the back, peak muscle strain occurs frequently in a magnitude above the maximal voluntary contraction (MVC)(Oksa et al. 1996). Muscle strain may exceed the MVC level even under +4 Gz loading in the cervical erector spinae muscles if the head is twisted out of its neutral position (Hämäläinen and Vanharanta 1992).

2.1.2 The anatomical roles of the neck structures

The cervical spine consists of the first seven vertebrae of the spinal column. The vertebral bodies carry the most of the axial loads in the cervical spine. These loads are transmitted through vertebral bodies by both the cortical shell and cancellous core. Facet joints share loads with intervertebral disks and provide stability. The highest pressure in the facet joints occurs during combined torsion, flexion and compression. (Panjabi and White 1990)

The six intervertebral disks form an articulation between vertebral bodies C2-3 and C7-Th1. A disk itself is composed of three components. The nucleus pulposus contains cartilage cells surrounded by a gelatinous matrix with water binding proteoglygans in a thin collagen network. The surrounding annulus fibrosus contains interlacing layers of collagen fibres of high tensile strength. Intervertebral disks are attached by connective tissue to the vertebrae while cartilage endplates separate the disk from the vertebrae. Compression loads cause pressure build-up in the nucleus, which in turn produces both central compression load and tension in the outer layers of the annulus. If the nucleus degenerates and becomes less gelatinous, it will be unable to bear pressure and compression loads will be transmitted direct from one vertebra to the other by way of the annulus. (Panjabi and White 1990)

Besides a disk seven ligaments connect one vertebra to the next. They are the anterior and posterior longitudinal ligaments, the flavum in the posterior wall of the spinal canal, three interspinosus ligaments and a supraspinosus ligament that joins the adjacent spinous processes. The ligaments provide tensile resistance when a functional spinal unit of two vertebrae and an intervertebral disk are subjected to complex forces and torques. However, since the critical load on the osteoligamentous human cervical spine is only about 25% of the mass of the average head (Panjabi et al. 1998), the majority of the mechanical stability of the spine is due to its neuromuscular structures and control systems. There are more than 40 muscles, paired and symmetrical to the mid-sagittal plane, attached to the cervical spine (Lu and Bishop 1996). These neck muscles work as a groups of functional subunits on 37 joints to produce complex neck movements (Mayoux-Benhamou et al. 1990). There is a functional division between the surface and deep muscles. The Large muscles essentially counteract with gross external forces and handle movements, while forces transmitted by spinal column kinetics are controlled by the deep-layer system (Bergmark 1989). The splenius capitis, semispinalis capitis and cervicis muscles are mainly responsible for head extension (Conley et al. 1997). The sternocleidomastoid muscles are the main flexors, but they also rotate the head, bend it laterally and resist its extension from the neutral position. In addition, if other muscles in flexion or extension run obliquely and contract independently of the corresponding muscle on the opposite side, they rotates and bend the spine laterally.

The maximal isometric strength of the neck muscles diminishes downward to the cervical vertebral levels (Nightingale et al. 2002; Seng et al. 2002; Vasavada et al. 2001). Extension force or torque is greater than flexion force, and the neck rotator muscles have the least isometric force generating capacity among the functional neck muscle groups (Conley et al. 1995). Cervical musculature strength levels apparently vary with head-neck position and the direction of contraction. The maximal neck rotation strength is achieved with the head and neck are at the highest prerotation angles (Ylinen et al. 2003).

Helleur et al. (1984) have developed a sagittal plane mathematical cervical spine model to express the biomechanical equilibrium as a combination of external load, joint reaction force and ligament tension. This model has shown that accelerations of up to 30 Gz could be supported with the appropriate (neutral) posture and (axial) direction of acceleration. However, posture changes are an important factor in cervical load bearing tolerance. A cadaver study has demonstrated that load, required to produce failure was reduced by 50 % if the cervical spine was flexed or extended by 25 degrees (Maiman et al. 1983).

2.1.3 Normal cervical spine movements

Axial rotation takes place predominantly at the C1-C2 level. The range of motion (ROM) in flexion-extension is the greatest at occiput-C1 (extension; up to 20º) and C1-C2 (flexion; 12º) (Panjabi et al. 2001). In the lower cervical spine, the greatest flexion-extension ROM (20º) is in the C5-C6 segment, while the segments above this (C3-C5) have the greatest ROM in lateral bending, (11º). The sum of ROMs in all directions is greatest in C3-6 segments (White and Panjabi 1990), which may have significance with the location of injuries sustained under high Gz loading.

Active cervical movements are equal to maximal voluntary movements, but they do not represent the whole ROM, and it is possible to achieve additional (passive) motion in the cervical spine by imposing external forces (Dvorak et al. 1988). Lantz et al. (2003) draw attention to the use of a thoracic reference point during measurements of cervical ROMs. If thoracic reference is not attached to the test subject's body, the measurements appear to contribute overestimation, and for this reason, some earlier reports on cervical ROMs have shown a tendency towards giving greater values than other studies.

2.1.4 High-risk movements

As mentioned above, the cervical spine in its neutral position is capable of supporting large external loads. However, pilots are frequently exposed to high Gz with the head in a rotated and/or extended position while observing other aircraft.

Coackwell et al. (2004) and Snijders et al. (1991) described the high-risk movements as rotations that exceed 35 degrees, extensions that are beyond 30 degrees and flexions that exceeds 15 degrees as well as all lateral bending. Beyond these limits the efficiency and force-generating capacity of muscles decrease and the joint reaction forces tend to increase rapidly (Helleur et al. 1984; Mayoux-Benhamou and Revel 1993). Even though the diameter of the lower cervical neuroforamina (C5, C6, and C7) decreases with increased extension, there is not a significant decrease in the diameter of the foramina when neck is flexed or extended with axial rotation (Yoo et al. 1992).

"Check six" i.e. looking directly behind the aircraft, requires maximal neck rotation, often accompanied by extension and lateral bending (Newman 1997a). In the study by Netto and Burnett (2006a), head kinematics showed that "check-six" is closest to the end-range in any plane of movement (86% ROM in rotation) and also produces the greatest magnitudes of movements also in other planes. With the head posture close to the end range, high levels of neck muscle activation and co-contraction were discovered under high +Gz. The number of muscles involved, the intensity of contraction required, the limited force-generating capacity of the muscles during rotation, and the awkward posture all combine to make the "check six" extremely conductive to neck injuries (Coakwell et al. 2004).

2.2 Occurrence of cervical injuries

2.2.1 Prevalence rate

The reported prevalence of high Gz-induced musculoskeletal symptoms varies between 10% and 90% depending on the length of the surveyed period, maneuverability of aircraft flown and the age of subjects (De Loose et al. 2008; Hämäläinen et al. 1994a; Knudson et al. 1988; Newman 1997a; Vanderbeek 1988; Yacavone and Bason 1992). Most fighter pilots have experienced flight related musculoskeletal symptoms during their career.

2.2.2 Muscle and ligament injuries

Lower levels generally cause injury to the soft tissue elements of the neck (Green 2003). Ligamentous or muscle injuries are usually reported to take place when the head has been in a bent and rotated position, another pilot on board has initiated an unexpected high-Gz maneuver, or otherwise load exceeded the muscular performance for some other reason. These injuries usually occur in the lower part of the cervical spine, C5-C7 (Andersen 1988; Clark 1990; Schall 1989). As an utmost example, Oksa et al. (1996) reported an injury in the sternocleidomastoid muscle, when the Gz loading exceeds muscle's performance 2.5-fold during an in-flight EMG measurement.

2.2.3 Vertebrae and disk injuries

An acute injury to the hard tissues of the cervical spine occurs during high Gz loading in association with a soft tissue injury when supportive tissues are no longer performed optimally and fail to protect the spinal structures. Compression fractures, herniated intervertebral disks, and fracture of spinous process have been reported. These injuries usually occur in the lower part of the cervical spine C4-7 or in the associated disks (Andersen 1988; Clark 1990; Hämäläinen et al. 1994b; Newman 1996; Schall 1989).

2.2.4 The determinants of neck pain among fighter pilots

Flight hours

A Finnish study followed-up during one to three years a cohort of 66 fighter pilot trainees frequently exposed to high +Gz forces. Nearly 40% of them experienced some in-flight neck pain. The number of flight hours was found to be the only significant determinant of acute in-flight neck pain (Hämäläinen et al. 1994a). The most remarkable threshold was noticed at the point of 200 flight hours in the jet trainer syllabus (Rintala 2012). At this point, the prevalence of flight-related symptoms increased exponentially up to 600 flight hours.

Gz-exposure

The pilots of maneuverable fighters often report a higher rate of Gz-induced neck injuries or other flight related symptoms than other aircrew members do. Pippig and Kriebel (2000) compared German Air Force pilots with cervical or lumbar discopathies, and found that fast jet pilots experienced discopathies earlier than helicopter or transport pilots in relation to flight hours. Landau et al. (2006) used similar subgrouping, but their limited material was non-selected, and degenerative changes in the cervical spine seemed to be associated with age rather than aircraft type, affecting the older group of transport pilots more than the group of younger fighter pilots frequently exposed to high +Gz.

Muscle strength

Since it has been suggested that muscular strength has a link with susceptibility to in-flight neck injuries and their prevention, various muscular conditioning programs have been recommended (Burton 1999; Coakwell et al. 2004; Kikukawa et al. 1995; Newman 1997a; Vanderbeek 1988; Yacavone and Bason 1992). There is also reports on their beneficial effects in terms of reduced symptoms (Hämäläinen et al. 1993a; Äng and Harms-Ringdahl 2006). However, there are not controlled studies that would have shown a direct relationship between neck muscle strength and the reduced risk of acute neck injury. On the other hand, pilots will in any case experience loads that exceed their tolerance. Oksa et al. (1996) reported that during air combat sortie, all monitored pilots exceed their maximal electromyography (EMG) activity measured during maximal voluntary contraction (MVC) in every applicable muscle.

A Swedish study (Äng et al. 2005) showed that, fighter pilots who had neck pains had a significantly lower extensor MVC than pilots without neck pain, while there was no such difference among helicopter pilots or between the two groups without pain. Yet, it is difficult to establish whether pain causes lower muscular strength or less muscular strength leads to neck pain and injuries.

Head position

The biomechanics of high-risk movements were considered in Chapter 2.1.4. Extreme neck extension with or without rotation is very common in air combat and it is associated with high levels of muscle activation and fatigue. In a study by Green and Brown (2004), the head was out of the neutral position for 68% of the time during air combat maneuvering, predominantly in extension, or in rotation plus extension. Similarly, an Australian study determined the "check six" head position as a causal factor in most neck injuries (Newman 1997a).

Thuresson et al. (2003) suggested that increased loads caused by different head positions may have a greater influence on muscle activity than the increased mass of the headgear. Hence, head positions determined in this study did not include extreme or maximal voluntary movements.

Life support equipment

Biomechanical calculations and modelling indicate that helmet-mounted devices (HMDs) increase the neck load substantially, and that centre of gravity (CG) offset has a significant effect on head-neck torques, contact forces, and neck flexion angles (Lee et al. 1991).

It has been documented that the extra mass of a helmet, CG shift, and enhanced head movements all increase the workload of the cervical muscles and potentially lead to a greater incidence of +Gz induced neck injuries (Ashrafiuon et al. 1997; Hoek van Dijke et al. 1993; Kumar et al. 2002; Newman 2002). Neck pain is also common among helicopter pilots, who seem to have more symptoms due to muscular fatigue while using HMD (Äng and Harms-Ringdahl 2006).

Various methods of head fixation to prevent cervical injury have been demonstrated. These include cervical collars, inflated thoracic defensive members, airbags, cervical supports, and others, but all have some deficiencies related either to one-time availability or the restricted range of head motion they allow (Panin and Prusov 2001). Moreover, all these methods would be unable to preclude cumulative loading and resulting effects on degenerative processes.

An inflatable neck bladder incorporated in many modern helmets supports the neck and prevents the helmet's slipping under high Gz. Pilots have given positive feedback about support by the bladder (Siitonen 2000). However, there seems to be no published data on the effects of the bladder on neck muscle strain.

2.3 Degenerative changes in the spine

The degeneration of the spine is the combination of degenerative lesions of intervertebral disks and spondylosis. Although degenerative changes of the spinal column correlate with age (Abdulkarim et al. 2003; Boden et al. 1990a; Boden et al. 1990b; Erkintalo et al. 1995), radiological findings are often apparent even among young people (Hald et al. 1995a).

2.3.1 Association with Gz-exposures

High Gz exposure puts the human spine under great stress. Hämäläinen et al. (1996) measured that 40 minutes of high +Gz maneuvering reduced body height by average 5mm. Repeated frequently, this kind of pumping effect could contribute to premature degenerative changes in the intervertebral disks.

Radiological studies have shown early degenerative changes among military pilots, especially in the cervical spine. It has been found that pilots of high-performance fighters have an increasingly high rate of spondylosis in the cervical spine compared to the controls (Hendriksen and Holewijn 1999). it has also been suggested that cervical spinal canal stenosis is linked with Gz-exposure (Hämäläinen et al. 1999). Studies using magnetic resonance imaging (MRI) have revealed a significantly larger number of degenerative changes in the cervical canal among experienced fighter pilots compared with their age-matched controls (Hämäläinen et al. 1993b; Petren-Mallmin and Linder 1999). A re-evaluation of their subjects by Petren-Malmen and Linder (2001), undertaken after a 5-year follow-up, showed diminishing changes both between experienced pilots and their non-flying controls and between experienced and young pilots during this period. Another study linked degenerative changes in the cervical spine with older age rather than aircraft type flown (Landau et al. 2006). However, the NATO Acceleration Panel's meta-analyses of international studies demonstrated positive association between exposure to sustained Gz and degenerative changes in the cervical spine (Burton 1999).

2.3.2 Relationship between acute injury and degeneration

The relationship between acute injury and degenerative changes in spine is explained with the theory of cumulative trauma: sustain exposure to high Gz loading causes muscle pain or tenderness, resulting in muscle spasm and impaired muscular performance. This in turn leads to soft tissue (muscle or ligament) injury, and destabilization of the spine. Unstable spinal structures increase intervertebral disk load, which leads to disk degeneration and later to spondylosis (Burton 1999). The observations of other studies' support this chain of the theory (Hendriksen and Holewijn 1999; Oksa et al. 1999).

2.4 Factors contributing to cervical loading

High Gz loading during sorties causes frequently peak strain that is above the magnitude of the maximal voluntary contraction of the muscles. In the cervical flexors (SCM) and in the erector spinae muscles especially, the peak strain presents a potential risk of injury and negative health effects (Oksa et al. 1996). Additionally, it has been suggested that certain environmental, equipment-related as well as fatigue and recovery associated factors contribute to the musculoskeletal loading of the pilots of high performance aircraft.

2.4.1 Environment

Cold exposure

A survey conducted by the Aero Medical Centre of Finland to all fighter pilots and their follow-up during annual examinations has shown that occupational neck disorders and high-G related neck pain disability are more frequent among pilots posted to the northernmost squadron in Rovaniemi (66.6°N, 25.8°E) compared to other squadrons based more to the south (61-64°N) (unpublished observations). Winters in the north are longer and colder (Drebs et al. 2002).

The neck area is the most lightly clothed part of the body of a fully kitted-out pilot. In a cold environment neck muscle temperatures are likely to diminish until the cockpit warms up after take-off. It is known that with subnormal muscle temperatures the efficiency of muscular performance is markedly lower than with normal muscle temperature. The association between cold exposure during work and musculoskeletal complaints or diseases has been reported (Jin et al.

2000; Pienimäki 2002). Even a very superficial cooling suffices to reduce performance substantially (Oksa and Rintamaki 1995). The maximal force production and co-ordination of muscles diminish in a cold environment (Denys 1991; Oksa et al. 1995), especially in dynamic work. Similar changes in muscular performance are apparent in static work; although the degree of performance decrement may be lower (Holewijn and Heus 1992; Krause et al. 2001; Thornley et al. 2003). Exercises that seem to be the most susceptible to cooling are dynamic and short, and they involve fast movement and/or the elastic properties of the working muscles. Repetitive work in a cold environment in particular, causes higher EMG activity and fatigue than work in thermoneutral conditions, thus possibly creating a higher risk of overuse injuries (Oksa et al. 2002).

There is a dose-dependent response between the degree of cooling and the amount of decrease in muscle performance as well as EMG activity changes. A relatively low level of focal cooling is sufficient to decrease muscle performance significantly (Oksa et al. 1997).

2.4.2 The helmet and helmet-mounted devices

It has been reported that helmet weight alone increases muscle strain by 15% under high Gz (Hämäläinen 1993b) and aggravates fatigue in the cervical area (Phillips and Petrofsky 1983a, 1983b). Ultimately, the increased mass of the helmet system combined with a high ejection seat acceleration results in increased neck compression force which may even exceed the established cadaver injury limits (Buhrman and Perry 1994).

Helmet-mounted devices (HMD)

Helmet-mounted devices (HMD), not only add to the weight of the helmet system bur also shift its center of gravity, and therefore they have significant effects on cervical loading and may lead to the greater incidence of +Gz induced neck injuries (Ashrafiuon et al. 1997; Hoek van Dijke et al. 1993; Kumar et al. 2002; Newman 2002). When Phillips and Petrofsky (1983a) measured different head loading configurations and their effects on weight and CG combinations, they found a significant reduction in the endurance of the cervical muscles when head load was increased.

Biomechanical calculations and modeling indicate that HMD increase the neck load substantially, and that a CG offset has significant effects on head-neck torques, contact forces, and neck flexion angles (Lee et al. 1991). The muscle activations required to balance the head and neck in extreme postures increased the compressive force in the lower part of cervical spine substantially, while in a neutral posture the muscle activations remained low. According to model of Mathys and Ferguson (2012), the lateral neck muscles can reach MVC and cause compressive joint forces up to 1100N during extensive rotations and extensions at high Gz. The mean muscular activity in EMG in the cervical muscles was significantly higher with subjects wearing a helmet and night vision goggles (NVG), or the helmet, NVG and a counterweight, compared with results obtained when they wore a helmet alone (Thuresson et al. 2003). Similar findings were reported by Knight and Barber (2004), who demonstrated that measured EMG activity in the cervical flexors, and especially in the extensor muscles, increased with an increase in frontal load. These two studies also showed that neck posture and movements might be even more significant than the weight of a headgear in certain situations. These studies were, however, carried out in a +1Gz environment.

Head movements

Hämäläinen et al. (1992) studied muscle activity (EMG) during test flights in the BAe Hawk and found that muscular strain increased with increasing Gz forces and head movements. Under +7.0 Gz the mean muscle activity (EMG) was 5.9-fold compared with +1.0 Gz and was 37.9% of the maximum voluntary contraction (MVC). In some individuals, the muscular tolerance (100% of the MVC) was ipsilaterally reached already under +4.0 Gz with concomitant movements and twisted head positions. Several normal postures of an F-16 pilot were analysed with a biomechanical neck model, and accelerations and head positions were measured during four flights. With the help of a model, muscle forces and joint reaction forces in the neck were estimated. It was recommended that these forces be reduced by lightening the helmet or shifting its centre of gravity aft (Hoek van Dijke et al. 1993).

Head movements increases when the field of vision is reduce due to watching through goggles or a pinhole. In the study of Ineson et al. (2004), participating aircrew were asked acquire static targets using head- or eye-aiming, maintain the acquisition while the target was lit, and then switch to the next target as quickly as possible. This was done during a centrifuge provided sustained accelerations of up to +8 Gz. Eye-aiming acquisition times and accuracy were affected only slightly by Gz; however, both head-aiming speed and accuracy deteriorated with increasing Gz. Eye-aiming was substantially faster than head-aiming at all Gz levels, but head-aiming was more accurate under these experimental conditions. These head movements result in increased muscle activity under Gz.

2.4.3 Fatigue

Phillips and Petrofsky (1983a) measured different head loading configurations and their effect on weight and CG combinations. They found a significant reduction in the endurance of the cervical muscles when head load was increased. Similarly, when the effects of repeated air combat maneuvering were studied (Oksa et al. 1999), the fatigue was observed in every applicable muscle.

It was greater in the neck area, which may increase the risk of neck injuries, and thus reduce the mission effectiveness. A comparison between fighter pilots who suffered from frequent neck pain and their pain-free controls showed no difference in terms of fatigue (Äng et al. 2005).

2.5 Factors reducing cervical loading

Pilot selection procedures

More careful pilot selection procedures have been recommended as a preventive method for the occupational health problems. Some reports have discussed radiological findings among pilot applicants, but studies of selection procedures are lacking. Otherwise, there is a lack of published studies of pilot selection procedures. Van Leusden et al. (1991) reported that 17% of permanent groundings of Canadian Forces pilots were due to orthopaedic disorders, mainly pain in the lower back, and highlighted the importance of spinal screening during selection process. Among the selected population of 232 Norwegian military pilot applicants, the spinal radiographs of only 1/3 of them were considered normal, while 1/10 of the applicants were rejected from military flight training due to radiological findings (Andersen et al. 1991). A German report covering 10,922 asymptomatic pilot applicants stated that only 3 % of them were “normal”; i.e., they had no morphological changes in spinal X-rays (Hald et al. 1995a).

2.5.1 Ergonomics

Cockpit ergonomics

Sitting postures and ejection seat angles also need to be addressed when considering pilots’ musculoskeletal loadings under hypergravitational forces.

A fighter cockpit is a compromise between limited space, the placement of controls and ejection seat requirements. Cockpit ergonomics have not been studied to any significant extent, even though there are some reports on ergonomics and muscle strain in helicopters. Height has been a significant predictor for in-flight low back pain among U.S. Navy helicopter pilots studied. BMI, total flight hours and helicopter type flown were not predictable (Orsello et al. 2013). For every 1 inch increase among male pilot height values, the odds of experiencing substantial back pain in flight increased by 9.3%, with those taller than median (71in/180cm.) having over twice the odds compared with those shorter. Helicopter pilots do not maintain a symmetric posture and they are contracted on one side more than on the other. Studies on the effects of this asymmetry have yielded contradictory results: Lopez-Lopez (2001) reported a statistically significant increase in right-sided lumbar activity related to flight duration but, another study fail to prove that lumbar back pain in helicopter pilots would be caused by erector spinae muscle stress (de Oliveira et al. 2001).

Effect of seat-back angle

A review article suggested that of subjects occupying a car seat with backrest inclinations of 110 to 130 degrees and wearing a concomitant lumbar support were subjected to the lowest intervertebral disc pressures and showed the lowest EMG recordings from the spinal muscles (Harrison et al. 1999). This finding was supported by clinical outcome from another car driver study, where the prevalence of lower back pain was five times greater among subjects with back-thigh angle of less than 86 degrees compared to those with a back-thigh angle of greater than 91 degrees (Chen et al. 2005). Yet, an increase in the back-rest angle has only a minor effect on lumbar lordosis (Andersson et al. 1979).

On the other hand, the more backward inclined (120 degrees) backrest of the F-16 seat decreases the lordosis of the cervical spine (Hoek van Dijke et al. 1993), which in turn increases compressive forces and intervertebral disc pressure (Harms-Ringdahl et al. 1986). It has been determined that this has a bearing on the high incidence of cervical disorders among F-16 pilots (Hendriksen and Holewijn 1999; Jones et al. 2000).

Head support

Reports show that pilots can reduce cervical loads by wedging or bracing the head against aircraft structures prior to the application of +Gz (Newman 1997b). As a result, the total mass of the head and helmet system is not borne by the neck structures. In a study by Green and Brown (2004) the strain of neck erector spinae was halved when the canopy was used as a support.

Lumbar support

It is hypothesised that a lumbar support could reduce muscle strain in the lower back under Gz and it might alleviate cervical muscle strain, due to a more ergonomic sitting posture it enables. If the seat fails to support the lower back adequately, the pilot will slump into the seat under high Gz and lumbar lordosis decreases. This results in a forward inclined upper torso posture, which in turn is compensated by the extension of the cervical spine in order to maintain an optimal eye position in the cockpit.

Since 1973, all Royal Air Force aircrews who suffer from lower back pain have had the opportunity of using a lumbar support. Fast jet (Tornado, Jaguar, Harrier and Hawk) pilots have also received these supports. However, nowadays most (73 %) of the lumbar support users are rotary wing pilots (Winfield 1999). There were 33% of RAF helicopter pilots who used a back support (Cunningham et al. 2010).

It has been reported that a lumbar support enhances the effectiveness of muscular work during an anti-G straining maneuver (AGSM). This has been explained by the more optimal muscle length of the torso muscles due to the more upright position of the spine, which in turn enhances a muscle's ability to generate required force the during an AGSM (Oksa et al. 2003).

2.5.2 *Physical conditioning*

Physical fitness has been seen as an essential contributor to successful performance in military aviation since the introduction into service of maneuverable aircraft. Finnish pilots performed physical tasks like digging and fortification during the Continuation War 1941-44 in order to improve their physical conditioning in addition to of force protection. Epperson et al. (1982, 1985) later demonstrated that weight training improves human tolerance to air combat maneuvering and Gz in terms of prevention of the G-induced loss of consciousness.

Warm-up

In sports, warm-up is regarded as a method for preventing injuries and enhancing the performance in terms of more optimally working muscles. Stewart et al. (2003) studied the effects of warm-up on muscle electrical activity. Active warm-up altered the EMG median frequency, this would be relate to a greater conduction velocity, which in turn might lead to faster activation of the muscle fibres, and this could partly explain the increase in power output.

Muscle strength training

As the fundamental problem lies with loading and load-carrying capability, it is logical to assume that more muscle strength would give more support. Therefore, many suggestions for better muscular conditioning have been presented.

As described earlier, a follow-up study showed that the frequency of muscle endurance training was the only possible determinant related to experienced acute in-flight neck pain (Hämäläinen et al. 1993a). Later Rintala (2012) found that higher neck flexion forces are related to a reduction in the flight related musculoskeletal symptoms. A similar trend was found in a survey conducted among Swedish helicopter pilots (Äng and Harms-Ringdahl 2006). In another

Swedish study, pilots were divided into two subgroups for specific neck exercises. One of these performed exercises under control and supervision during a six-month-period while the control group received just an overview of the programme at the beginning. Exercises increased the strength and endurance of the cervical muscles in the supported group, whereas the unsupported group had lower extensor strength and endurance upon the completion of the programme. Yet, no significant changes in the frequency of neck complaints were reported in either group, which reflects the need of individual approach to any rehabilitation programme (Alricsson et al. 2004). More sophisticated and strict guidance during training period gives results. Twenty-four weeks of targeted training combining deep neck muscle, strength, and endurance training proved effective in reducing neck pain among Danish fighter pilots (Lange et al. 2013).

Specific training methods

Studies that would actually present methods of reducing pilots' cervical loading are practically unavailable. The lack of useful intervention studies makes it impossible to evaluate and establish different neck-specific training regimens and techniques or to compare the effectiveness of general whole body conditioning with results obtainable with neck specific training methods.

Hämäläinen et al. (1998) compared two training methods: general muscle strength training and specific neck training with a helmet fitted with additional weights. Neck muscle strength increased similarly in both groups, but the incidence of acute neck injuries did not reduce during the follow-up of 1-3 years. Nevertheless, pilots doing dynamic exercises had fewer sick leaves and +Gz restrictions than pilots doing helmet exercises. The study of Burnett et al. (2005) compared a multi cervical unit (MCU) group with an elastic band group. The MCU resistance machine was a more effective training modality for the increased isometric strength of the cervical muscles, while elastic band tubing produced moderate gains in isometric neck strength. When differences between results are interpreted, it has to be noted that both groups were tested with the MCU group's training device, which may have influenced measurements. Unlike the resistance machine, the elastic band cannot produce muscle activity levels obtained under high Gz, yet it can be a useful means for the low intensity, endurance-type training of the cervical muscles (Netto et al. 2007).

Balance training performed on instability training devices such as a rolling board, mini trampoline or large rubber ball is an effective means of gaining a degree of muscular strength and in contrast to strength training, of equalising muscular imbalances. One possible training method is the Aerotrim, used to train balance and equilibrium e.g. among astronauts. It produces high onset rate movements about the three axes of motion in a random order. These rapid changes in the direction of movement also load the cervical muscles when subject is maintaining head balance. While this training method is used primarily for equilibrium training, it could be applied with beneficial effects on muscle co-ordination in a three-dimensional environment under various loading vectors.

It is maintained that pilots should carry out “specific and intensive” training (Coakwell et al. 2004). High-Gz flying can be considered to fall in this category An Australian study suggests that short-term exposure to limited +Gz loading during eight months of flight training caused no changes in strength values except for flexion force in the neutral position (Burnett et al. 2004). When the overall muscular strength of the neck of fighter pilots were examined (Seng et al. 2003), the values obtained did not differ markedly from those of non-pilots, nor did exposure to +Gz lead to specific changes in isometric muscle strength across any of the four principal directions. Only neck muscle strength in the four measured directions pooled across the two subgroups were statistically significant.

2.6 Methodological considerations

2.6.1 Imaging (MRI)

Magnetic resonance scans are more accurate than conventional radiographs due to their ability to demonstrate also intervertebral disk pathology. Other imaging modalities such as radiography, myelography and computer tomography (CT) may provide complimentary information in selected cases (Malfair and Beall 2007). A slight degree of degenerative changes are paraphysiologic and should be considered pathologic only if abnormalities determine symptoms (Gallucci et al. 2007). The significance of radiological findings needs to be discussed, however. Recent literature presents that nerve compression is an important finding that may contribute to the prediction of symptoms (Beattie et al. 2000; Elfering et al. 2002). Association between recent lower back pain and endplate changes, disk degeneration, annular tears or facet degeneration has not been determined to be a risk factor in a three-year follow-up (Jarvik et al. 2005).

In radiological terms, the degeneration of the spine is defined as the loss of disc height, reduced disk and bone marrow signal intensity, and disk protrusion or herniation shown on magnetic resonance imaging (MRI) (Fardon et al. 2001; Kjaer et al. 2005; Kolstad et al. 2005; Luoma et al. 2001; Pfirrmann et al. 2001; Thalgott et al. 2004). The reduced signal intensity of a disk is the most common sign of disk degeneration shown on MRI. Even though reduced signal intensity and disk height are generally accepted as an indicator of disk degeneration (Osborn 1994), the signal intensity of nucleus pulposus seems to be a more feasible measure than absolute disk height (Luoma et al. 2001). In addition, the high intensity zone (HIZ) is particularly diagnostic for painful internal disc disruption (Aprill and Bogduk 1992). It is also assumed that vertebral endplate changes are associated with degenerative intervertebral disk disease (Kokkonen et al. 2002; Kuisma et al. 2007).

Since radiographic findings are common among asymptomatic young people, they are also apparent among pilot applicants (Andersen et al. 1991; Hald et al.

1995b). In a group of young inexperienced Swedish pilots (average age 23 years, 220 flight hours), cervical MRI showed a low frequency occurrence of low-grade degenerative lesions (Petren-Mallmin and Linder 1999). Similarly, the higher frequency of disk degeneration, defined as disk height reduction on conventional radiographs and reduced disk signal intensity on MRI, has been found among wrestlers and gymnasts than among non-athletes. The abnormalities of the vertebral bodies including abnormal configuration, Schmorl's nodes and apophyseal changes are common among athletes (Sward 1992), but these findings are at least partially due to the fact that athletes start their training at younger ages and the risk of injuries is higher with a growing individual. The spine, like the rest of the skeleton, is at the greater risk of injury during growth, especially during the adolescent growth spurt.

2.6.2 Electromyography (EMG)

EMG is a valid method for the measurement of muscular activity and strain, but the measurements and the evaluation of the results should be done with care. Recommendations have been established for this purpose (Hermens et al. 1999). The placement of the electrodes is critical for the reliability of measurements, and the coefficient of correlation between force and an EMG signal may vary significantly depending on their placement (van Dieen et al. 1991). It has also been suggested that muscle fibre composition affects on the measured activities (Woods and Bigland-Ritchie 1983), which should be taken account when results are interpreted.

Variation exist between independent contractions; however, when force production efforts were averaged, high reliability was found for both surface and intramuscular electrodes (Burnett et al. 2006), as well as for within day and between days MVC measurements (Netto and Burnett 2006b).

A study series by Kumar et al., determined the effect of the grade and direction of force output in the cervical muscles in terms of EMG parameters median frequency and mean power frequency. They found that EMG is dependent on both the force produced (Kumar et al. 2001) and the direction of effort (Kumar et al. 2003; Kumar et al. 2002).

Low ambient temperature causes focal cooling affects muscular performance, and differing results have been reported of the measurements of the direction and quantity of the EMG amplitude response to changes in tissue temperature. The amplitude of surface EMG tracings seems to be a reliable parametre of muscle force, whereas turns are sensitive to temperature. Still, an EMG analysis can be performed without temperature monitoring if severe cooling does not occur (Finsterer and Mamoli 1996; Krause et al. 2001). On the other hand, when EMG is used during high-intensity, dynamic activities that increase muscle temperature, the efficacy of measurements is improved with temperature adjustment (Madigan and Pidcoe 2002). Winkel and Jorgensen (1991) have reported that when skin temperature above muscles decreases from 33°C to 22°C, the EMG amplitude is broadly doubled. However, Bertram et al. (1995)

reported to the contrary, that there were no significant differences in amplitude or turns, and that focal cooling induced prolonged motor unit action potential and increased motor unit action potential frequency. Holewijn and Heus (1992) reported that cooling resulted in a significant decrease of 20 % in the maximal force and a significant 50 % decrease in force build-up time, median power and in the maximal rhythmic grip frequency. No EMG changes due to temperature changes were discovered during static muscle activation.

The relationship between EMG amplitude and tension for short-duration isometric contractions is nearly linear; however, increase in the amplitude reduced with the lowest muscle temperatures (Petrofsky and Laymon 2005). EMG amplitude can be used to measure muscle strain in most physiological conditions, but the frequency components of the EMG are related to temperature and therefore restricting the applicability of this method. The cooling of muscles affects the rates of contraction and relaxation in the same manner as fatigue, yet it has no effect on the firing rates of motoneurons (Bigland-Ritchie et al. 1992; Mucke and Heuer 1989).

3 The aims of the study

The present study was designed to examine the effects of high-Gz induced musculoskeletal loads on the fighter pilots’ neck.

The specific aims were:

- To study longitudinally degenerative changes caused by high-Gz exposure in the cervical spine.
- To study the effects of a cold environment and the extra weight of the helmet-mounted devices on neck muscle strain under Gz.
- To study the effects of individually adjusted lumbar supports on neck and back muscle strain.
- To study the effects of specific training programmes in reducing neck muscle strain under Gz, and to evaluate the sustainability of the possible effects of these programmes after a three-month follow-up.

4 Materials and methods

4.1 Subjects

In Study I, the test subjects were 12 Finnish Air Force (FINAF) cadet pilots and their age-matched non-pilot controls. The baseline MRIs of the cervical and lumbar spine were obtained at the beginning of the subjects' military training syllabus when the pilot group had not yet been exposed to high +Gz forces. The controls were Army and Navy cadets from the same annual cohort as the subjects. Based on the general military selection criteria for all military careers, the control group was assumed similar to the pilot group with regard to contributing factors such as social background, physical fitness and smoking, and having no degenerative or other chronic illnesses, yet they would not be exposed to flying induced stresses during their career. The subjects had no history of noteworthy spinal complaints at the beginning of the study. Follow-up MRIs were obtained 13 ± 0.8 years later to 12 pilots and to 11 controls. After the follow-up the total mean accumulated flying time of the pilot group was 1500 ± 390 hours, and flying time in high-performance aircraft (BAe Hawk, Saab Draken, MiG-21 and F-18), capable of high-Gz maneuvering, was 1200 ± 470 h.

In Studies II (ambient temperature) and III (helmet and NVG), the subjects were 14 volunteer FINAF cadet pilots (one female). At the time of the measurements, they were in the early stages of their fast jet training and were therefore having their first exposures to high Gz. All were fit to fly and none had existing or previous neck pains or other neck disorders. They did not participate in any supervised, specific neck-training programme, but they were all trained to exercise with the trampoline.

The evaluation of the effects of a lumbar support (Study IV) used 11 FINAF pilots as subjects. Even though they had no previous history of noteworthy spinal complaints they had experienced some flying-related musculoskeletal symptoms. Since an EMG analysis could not be completed on three subjects due to technical problems, their data were excluded from the muscular activity analyses.

For Study V (training intervention), 16 voluntary FINAF cadets were divided into strength training group (STG) and trampoline training group (TTG).

The basic descriptive determinants of the subjects are shown in Table 1.

.

Table 1 The anthropometric determinants of the subjects in the studies. The figures are means with standard deviation (±SD).
STG = strength training group, TTG = trampoline training group

	Subgroups	n	Age (yr.)	Height (cm)	Weight (kg)	BMI
I	Pilots	12	20.9±0.6			
	Controls	11	21.4±1.0			
II		14	21.5±0.9	178.3±0.1	74.0±8.2	23.2±1.9
III		14	21.5±0.9	178.3±0.1	74.0±8.2	23.2±1.9
IV		11		179.0±5.0	77.0±8.0	24.0±2.0
V	STG	8	22.1±0.6	178.5±4.6	77.4±6.5	24.3±1.1
	TTG	8	22.6±0.9	177.5±4.9	76.3±6.8	24.2±1.5

4.1.1 Ethical approval

The subjects of studies were informed of the details of the experimental protocol. The study was approved by the Finnish Defense Forces Medical Research Register, the Finnish Air Force Headquarters, which granted a Research License, and The Ethical Committee of the Central Finland Hospital District.

4.2 Methods

4.2.1 Magnetic resonance imaging (I)

Baseline MRI was performed with a 0.1T device (Mega 4, Instrumentarium, Finland). Follow-up MRI examinations were performed with a 1.0T device (GE Signa Horizon, UK). Both examinations included T1 and T2 weighted sagittal and axial MRI of the cervical and lumbar spine.

Two experienced neuroradiologists evaluated the images blinded to group information, and their agreement grades were used for data analysis. As the baseline images of three subjects were not available for evaluation, baseline data of the respective images was collected from earlier evaluations carried out by one of the grading neuroradiologists.

The signal intensity of the nucleus pulposus of the intervertebral discs C2-3 – C6-7 and L2-3 – L5-S1 was visually estimated using cerebrospinal fluid (CSF) at the corresponding level for intensity reference. T2-weighted images were used, and signal intensity was graded 0-2: 0 = normal signal intensity; 1 = intermediate intensity; 2 = dark nucleus pulposus. Disk height was compared with the height of the disk above, or if this was considered abnormal, with the nearest disk regarded as "normal". Disk height was graded 0-2: 0 = no or less than 25% reduction; 1 = 25-50% reduction; and 2 = more than 50% reduction. Disk bulging was evaluated in T1 and T2 images and graded 0-2: 0 = normal; 1 =

protrusion; 2 = extrusion and/or sequestration. High-intensity zones (HIZ) and end plate changes were described as not present or present, graded 0 or 1, respectively. All other findings observed from images were listed separately.

4.2.2 Electromyography (II - V)

Muscle strain was measured with a portable eight-channel EMG device (ME3000P, Mega Electronics Ltd., Kuopio, Finland). Bipolar EMG recordings were obtained using pregelled surface electrodes (Medicotest M-OO-S, Olstykke, Denmark).

During exercises and test flights, the EMG activity of the right and left sternocleidomastoid (SCM), cervical (CES) and thoracic erector spinae (TES), and trapezoid (TRA) muscles was measured using bipolar surface electrodes placed longitudinally on the muscles 2 cm apart (Figure 2) (Hermens et al. 1999). In Study IV, the EMG measurement of the TRA was changed to the lumbar erector spinae muscles (LES) due to the limited number of channels available. The ground electrodes were placed on inactive tissue. Electrode positions were marked on a clear plastic film using anatomical marks such as moles and scars for reference thus ensuring that the electrodes were replaced in exactly the same positions for follow-up measurements.

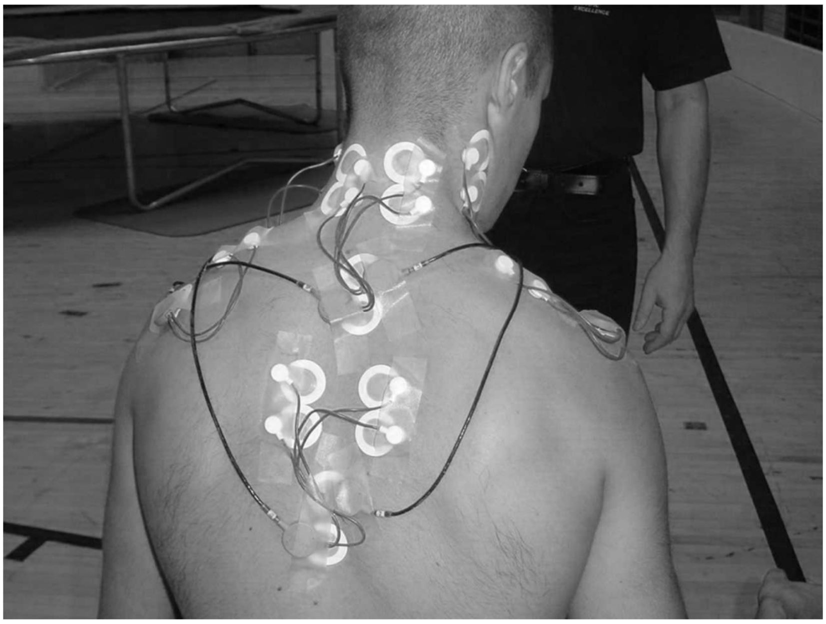


Figure 2 The placement of EMG electrodes

Measured signals were 1000 times preamplified. The signal band between 20 and 500 Hz was full-wave rectified and averaged with a 100-ms time constant. The measured EMG was compared with EMG obtained during isometric maximal voluntary contraction (MVC, see Chapter **Error! Reference source**

not found.). EMG levels and muscle strain were determined as a percent of MVC (%MVC).

Short “silent periods” of less than 10 µV for at least 300 ms in EMG activity were considered as EMG gaps. Their number and duration were analysed in Study V.

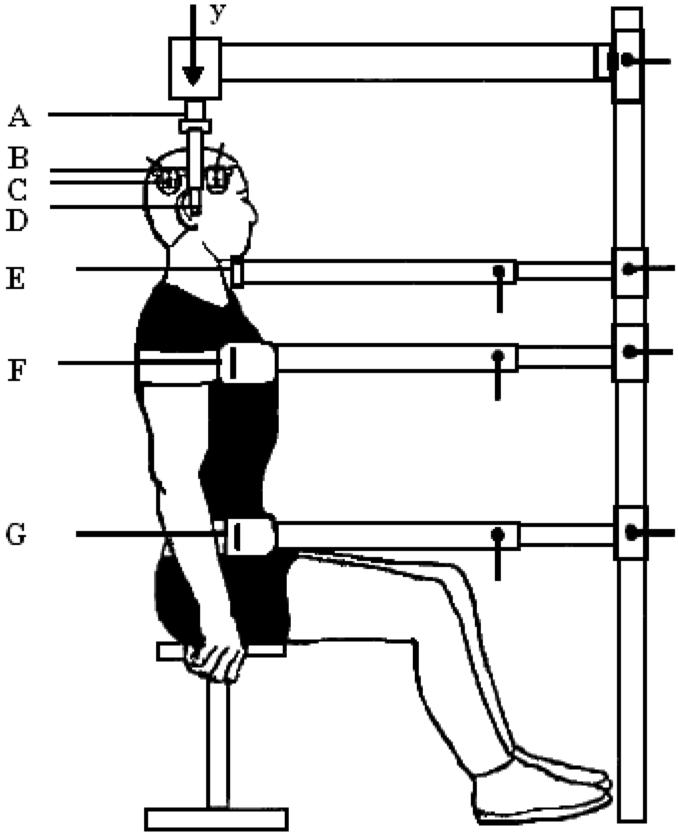
Cross-talk between near muscles underneath the surface electrodes were considered insignificant as electrodes were placed on the same positions and the analysed results were based on the changes between measurements, not on differences between measured values.

4.2.3 Strength measurements (V)

The muscle strength of the cervical flexor, extensor and rotator muscles was measured with an Isometric Neck Strength Measurement System, INSMS (Kuntoväline Oy, Finland) (Ylinen et al. 1999) before and after training period (pre- and post-test) in Study VI. The subject was seated facing towards the apparatus for testing rotation and flexion forces (Figure 3). For testing extension forces, he faced away from the apparatus. The load-cell was placed against the occiput at the same height as for flexion force measurement. After warm-up, he was asked to push/turn with maximal force three times in each direction with a pause of 45 s between each effort. The best of the three efforts was chosen for data analysis.

4.2.4 Maximal voluntary contraction (MVC)

Muscle activity (EMG) during MVC was used to determine the muscular strain as %MVC. MVC was performed as isometric contraction for cervical flexion (SCM), cervical extension (CES, TES) and shoulder rise (TRA) in Studies II, III, and V and additionally as isometric torso (lumbar) extension (LES) in Study IV.



4.2.5 *Figure 3 The subject is seated in a normal position with the head centralized by tightening the pads (C) simultaneously from both sides by a screw system travelling the same distance, so the sagittal plane is in the middle. The frontal plane along the rotation axis of the apparatus (y) is verified to run through the opening of ear canals by sights (D). The pads can be moved (B) to comfortable places on the skull. The cheek is supported (E) to prevent head movement. The chest (F) and waist (G) are tightly fixed to the bars with wide straps at the level of the iliac spine and above the lower border of the scapula. Rotational forces are recorded from the load-cell of the device (A). Load-cell (E) is moved upwards and placed against the forehead with the lower edge located midway between the inner canthus of the eyes to measure neck flexion force.*Skin temperatures (II)

Skin temperature on the trapezoid muscle was measured with a thermocouple (YSI 400 series, Yellow Springs Instrument Temperatures, Dayton, USA) and a datalogger (Squirrelmeter 1200, Grant Instruments, Cambridge, UK) before the walk to the aircraft and in the cockpit just before start-up and closing the canopy. Both measurements were done with the subject seated. Due to technical problems the measurements of the exposed SCM were unreliable in the prevailing freezing ambient temperature (-14ºC) and therefore they were excluded from the results.

Pre-flight skin temperatures on the apron

As part of active flight duty, walk to the aircraft (Hawk) and pre-flight checks before start-up and yet again time to the take-off were timed to be consistent with authentic exposure time for cooling. Subjects were informed about the purpose of the study and that measurements would not affect the sortie they were going to fly. They were asked to perform routinely and they were not aware of timing. The clothing was appropriate, uniform and controlled. The psychological effects of measurements were considered insignificant and thus their possible effects on skin temperature due to blood flow changes were excluded from analyses.

Muscle activity (EMG) measurements in two different temperatures on a trampoline

The thermoneutral, room temperature of +21ºC was considered a baseline for measurements. Exercises were performed in a random order. Outside temperature was an averaged -2ºC during previously determined measuring days. Due to the prevailing relatively mild winter conditions, the subjects were cooled down for 30 min at -2ºC before exercising in cold, which emulated cooling occurring during their flight duty as described above. Greater changes in skin temperatures were considered more valuable than identical cooling time with part one of the study, hence the aim was to measure the change of muscle strain due to different skin temperatures.

Skin temperature over SCM (exposed area) and trapezoids (unexposed area) was measured bilaterally (using the thermometer described above) in both conditions with the subjects wearing appropriate, standard winter and summer flight suits depending on the ambient temperature for a more realistic occupational setting. Since the sole objective was to determine the effects of low ambient temperatures on muscle strain, helmets were not worn in order to avoid unnecessary weight induced loads on muscles. For the duration of cooling and bouncing exercises in cold ambient temperatures, the subjects wore wool hats to avoid the cooling of head and unnecessary heat loss.

Environment

The measurements were performed at FINAF Training Air Wing, Kauhava, Finland (63.1°N, 23.8°E) in January. Ambient temperatures were provided by the installation's met office.

In the second part of the study, the test subjects performed trampoline exercises in two ambient temperatures, -2ºC (cold) and +21ºC (thermoneutral), which correspond to mild winter and summer conditions in Finland. Temperatures in Finland vary markedly across the country during winter, yet summertime temperatures are more equal. An average daytime high in July is around +21ºC in all locations of the FINAF fighter squadrons (Drebs et al. 2002).

4.2.6 Helmet and NVG (III)

In Study III, three sets of trampoline exercises were performed in a random order: without a helmet, with a helmet (Alpha, Helmets, Wheathampstead, GB; mass 1530g) and with a helmet and an NVG device (authentic replica, shape and weight as used in the FINAF: F4949 F, ITT-Industries, Roanoke, USA; mass 800g). Bouncing without a helmet was considered a baseline.

4.2.7 Test flights (IV, V)

In Study IV, the subjects flew two basic air combat maneuvering sorties with and without a lumbar support in a random order, and in Study V sorties were flown at the beginning and upon completion of the training period. The aircraft was the Hawk with a Martin-Baker Mk 10L seat with 107° backrest inclination and 94.5° thigh-back angle. The flights in Study IV or V were similar training sorties and consisting of aerobatics and basic tactical maneuvering, and they were executed according to sortie charts where the sequence of maneuvers and associated parameters (e.g. indicated airspeed, Gz, etc) were detailed. The number of times the levels of +0.25, +2.5, +3.5, +4.5, +5.5, +7.0 and +8.0 Gz were exceeded during the sorties was recorded by the aircraft's accelerometer.

4.2.8 Cervical loading test (V)

In addition to in-flight measurements, muscle activity (EMG) was also measured during a cervical loading test (CLT), in which the cervical flexor and extensor muscles were loaded separately. As the vertebral column and muscles have less range of movement in the lateral direction and therefore are more susceptible to injuries during lateral movements, lateral loads were not tested. Each neck movement, or strain against load, involves multiple muscles working together and, the same muscle may participate in different types of movement. Thus, all muscles involved in anterior flexion movements or strain against posterior loads were regarded as flexors, while all muscles involved in extension or strain against anterior loads were regarded as extensors.

In the test, subject was lying on the test table both in a prone and supine position with the shoulders on the edge of the test table, wearing a helmet with an external load suspended from an 8-cm elastic rope. The load for each subject was 25% of the maximal cervical extension force and 10% of the maximal cervical flexion force. The load was dropped 15 times from the frontal level (extensors) or from occipital level (flexors). When the load was dropped, the rope stretched approximately 6 cm and incurred an impact load on the muscle group involved.

The test was also performed three months later (follow-up) after a period of intensive flight training involving high +Gz exposure. The purpose of the CLT test was to exclude the effects of learning and improved flying skills during training and follow-up.

4.2.9 Lumbar support (IV)

An individually shaped lumbar support consisted of a slightly compressible Plastazote® polyethylene foam pad and an elastic band (80% of polyester and 20% of elastan). Its thickness varied from 7 to 15 mm. The support was not designed to push the lumbar spine forward for posture change; its purpose was to fill the gap formed by the lumbar lordosis between the back and seat. Before the final configuration of each lumbar support was determined, the support was test-sat in the Hawk seat, and the thickness or size of the support was altered based on each subject's opinion if required. The support was placed under the flight suit.

4.2.10 Trampoline exercises (II, III, V)

Basic bouncing simulates low Gz with the head in the neutral position. This exercise loads the muscles in the neck region, and was regarded as a warm-up before more strenuous exercises for straining the flexor and extensor muscle groups. During back bouncing, the subject bounces on his back, assisting bouncing with rhythmic arm and leg movements, while during hand and knee bouncing only hands and knees touch the trampoline during the contact phase. These exercises, respectively, load the cervical flexor and extensor muscles in particular. The subjects were asked to stabilize the head in the neutral position during all exercises to avoid whiplash-type movements caused by impulsive loads. Although the head is maintained in the neutral position during the exercises and the direction of loading is basically along x-axis, back bouncing is considered to activate the cervical flexor muscles in a manner similar to that experienced during the rotation and/or lateral bending of the neck during a "check six" or equivalent maneuver (Hämäläinen and Vanharanta 1992; Knight and Baber 2004). Similarly, hand and knee bouncing is considered to simulate situations such as a pull-up or head extension under +Gz.

Five equal-height jumps carried out by each subject were chosen for the analysis (II, III). The exercises were video recorded, and the height of jumps was measured from a scale behind the trampoline.

Gz measurements

On a separate occasion, vertical acceleration during bouncing were measured (n = 4) using a helmet-mounted MoTec ADL Datalogger and triple axis G-sensor (Printsport Oy, Lievestuore, Finland). These accelerations varied between 0 and +4 Gz (Figure 4). All subjects achieved similar acceleration levels in all exercises and despite minor differences in their mass and jump heights, the method was considered reliable for acceleration studies. In addition, the height of the jumps was matched when muscle strain was measured during the exercises. Thus, intraindividual accelerations were considered identical. A 4.3-m diameter round trampoline (JumpKing, Portland, USA) was used.

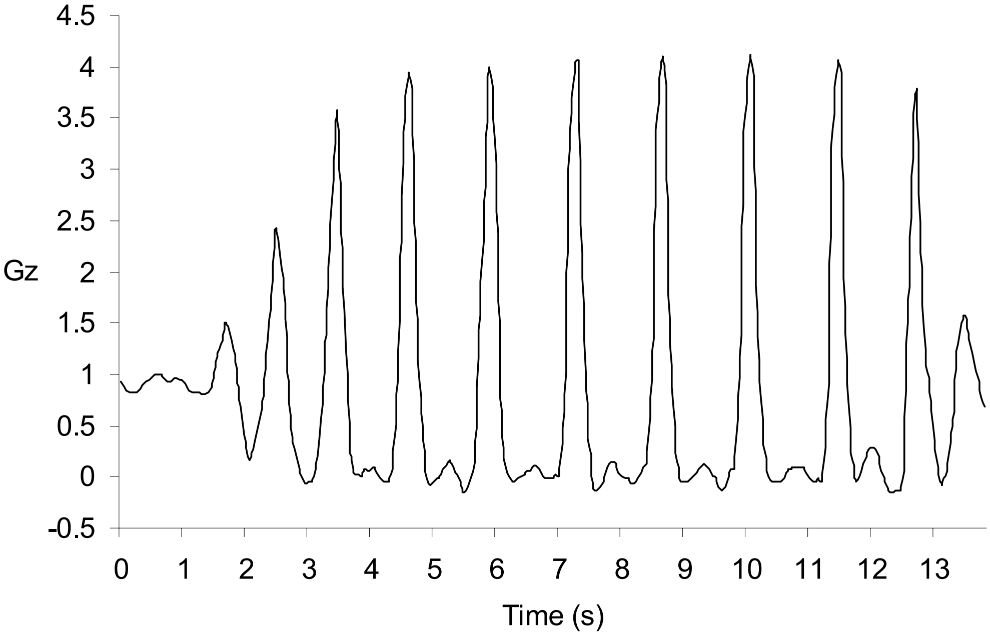


Figure 4 Accelerations during trampoline bouncing

The validity of the trampoline tests

Changes in ambient temperature did not change the characteristics of the trampoline. This was verified by dropping from a constant height a 5-kg gym ball attached with a MoTec ADL Datalogger and triple axis G-sensor (Printsport Oy, Lievestuore, Finland). Bouncing height and vertical acceleration were identical in both temperatures. Consequently, accelerations the subjects experienced were similar in both temperatures.

4.2.11 Training intervention (V)

Training programmes were part of the cadets' physical training. The cadets underwent an introductory phase where training methods and exercises were practiced to ensure they all had the required skills when training period commenced.

Training programmes

Training lasted 6 weeks and consisted of 2-3 exercise sessions per week. Training charts were prepared for the evaluation of the success of training.

The strength training group did cervical dynamic flexion and extension exercises and isometric rotation exercises. Each training session consisted of 2-4 sets of each exercise. The sets were 20-40 reps against the resistance of approximately 15-30 % of the measured maximal isometric force in the neutral position. Reps and resistance were increased progressively in every training week. The programme consisted of two three-week periods of easy, moderate and strenuous training weeks. A relatively low-intensity endurance-type approach was chosen to achieve increased endurance strength of muscle groups and to avoid overtraining or cervical discomfort caused by excessive loads.

The trampoline training programme consisted of basic trampoline exercises including basic, hand and knee and back bouncing. A 4.3-m diameter round trampoline (JumpKing) was used. The exercises were performed up to the limit of subjectively evaluated fatigue, normally in 30-60 s in one set with a similar 30-60 seconds recovery time between the sets. At the beginning of the training, each set was performed twice, and after two weeks, it was repeated three times.

4.3 Statistical analyses

Means with standard deviations (SD) or mean differences with 95 % confidence intervals (CI) are given as descriptive statistics. A t-test was used to assess the differences between groups (II, III, IV, V), and the changes of measured variables (II, III) were assessed using a paired t-test. In study I MRI findings were graded (from 0 to 1 or 2), and the changes of the graded findings during the follow-up were analysed with Fisher's exact test to determine differences between the groups (I). The relationship of skin temperature change and change in muscle strain under Gz (II) was analysed using a linear regression model. Changes in the skin temperature of the neck muscles (independent variable) and %MVC (dependent variable) were included in the linear regression analysis. The regression model was described using R^2 as the coefficient of determination. The analysis of variances with repeated measures was used to determine training effects, i.e., muscle strain after training and between the training groups (V). In all tests, p-value <0.05 was considered statistically significant.

5 Results

5.1 MRI follow-up (I)

All changes found in the cervical spine during the follow-up were minor in both groups. Where grade 2 would have been applicable, it was left unrated, however. Two cervical protrusions, one in the pilot group and one in the control group, were noted in baseline images, but not in follow-up images. One end plate deformation was noted in the control group during the follow-up; otherwise, there were no changes in protrusion, HIZ or endplates in the cervical spine. All other changes took the form of either reduced signal intensity or the reduced height of intervertebral disks. Although there were no significant differences between the groups, changes in the pilot group seemed to concentrate in the lower cervical spine, i.e., C5-6 and C6-7, while degenerative changes in the control group were scattered more evenly (Table 2).

Table 2 Changes in intervertebral disks observed upon comparing cervical MRIs at the time of initial pilot training and 13 years later.

	Pilots n=12	Controls n=11	p
Cases with disk degeneration	8	7	0.102
Affected disks per person (mean)*	1.25	1.71	0.137
C2–3 **	1	2	0.373
C3–4 **	0	1	0.478
C4–5 **	1	3	0.390
C5–6 **	3	4	0.296
C6–7 **	5	2	0.178

* Calculated as the total number of affected disks per group / number of affected subjects per group.

** The number of affected disks.

Two spondylolisthesis in the pilot group and one spondylolysis with olisthesis in the control group were diagnosed from the lumbar images, otherwise changes in the lumbar spine were only moderate. The occurrence of changes in the pilot group was higher in the signal intensity of disks, the height of disks, protrusions and end plates. Like in the cervical spine, changes in the pilot group were observed at a lower level, i.e. L4-5 – L5-S1. No statistically significant differences were found between the groups. (Table 3)

Table 3 Changes in intervertebral disks observed upon comparing lumbar MRIs at the time of initial pilot training and 13 years later.

	Pilots n=12	Controls n=11	p
Cases with disk degeneration	10	8	0.324
Affected disks per person (mean)*	1.50	1.50	0.183
L1–2 **	0	1	0.478
L2–3 **	0	1	0.478
L3–4 **	1	0	0.522
L4–5 **	8	3	0.060
L5–S **	6	7	0.267

* Calculated as the total number of affected disks per group/number of affected subjects per group.
** The number of affected disks.

5.2 Cold, Gz and muscle strain (II)

The walk to the aircraft and pre-flight checks before closing the canopy and start-up took an average of 6 ± 1 min. Time from the walk to take-off was 16 ± 3 min. Ambient temperature during measurements was -14.2 ± 2.2°C. Skin temperature over trapezoids reduced from 30.1 ± 1.7°C to 27.8 ± 2.6°C ($p<0.001$) during the time from starting the walk to the closing of the canopy.

When the subjects were cooled down in -1.5 ± 3.6°C before trampoline exercises in cold, skin temperature over the SCM reduced from 34.5 ± 0.6°C to 31.1 ± 2.1°C ($p<0.001$) and over the TRA from 34.4 ± 0.7°C to 33.5 ± 1.1°C ($p<0.001$). Skin temperatures did not change during the exercises.

Increase in muscle activity (EMG) was statistically significant in the SCM and CES in the uncovered area. No significant differences were noted in the lower muscles. Major deviation was observed in the thoracic muscles. (Table 4)

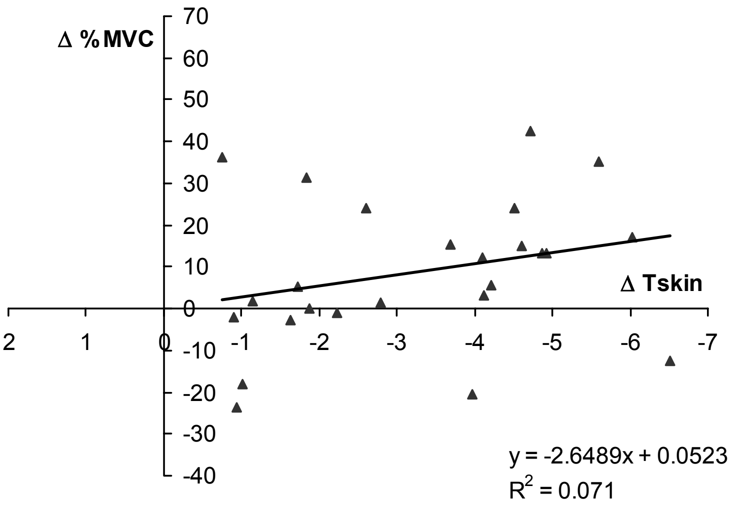
Table 4 The effect of ambient temperature on muscle strain (EMG) during G-loading on the trampoline. ΔMVC (%) is the percentile change of individual changes and therefore not equal to difference between averaged %MVC(+21°C) and %MVC(-2°C).

Muscle	%MVC (+21 °C)	CI (95%)	%MVC (-2 °C)	CI (95%)	ΔMVC(%)	p
SCM	45.5	40.1 to 50.9	50.5	44.3 to 57.3	11.0	< 0.001
CES	53.4	43.5 to 63.3	61.3	46.6 to 76.0	14.9	< 0.001
TRA	45.5	30.5 to 60.5	47.2	33.4 to 61.0	3.7	0.443
TES	49.3	38.9 to 60.3	48.2	39.4 to 57.0	- 2.1	0.452

SCM = sternocleidomastoides; CES = cervical erector spinae; TRA = trapezoids; TES = thoracic erector spinae; %MVC = muscle strain as the percent of the maximal voluntary contraction in a given ambient temperature

The regression model shows a 2.6 per cent unit increase in %MVC for every centigrade decreased in the skin temperature over the SCM. Measurements over the TRA present a major deviation in %MVC over a steep gradient of temperature change without correlation between variables. Pearson's correlation coefficients were 0.27 and 0.18, respectively (Figure 5).

A: Skin Cooling and Muscle Strain in SCM



B: Skin Cooling and Muscle Strain in TRA

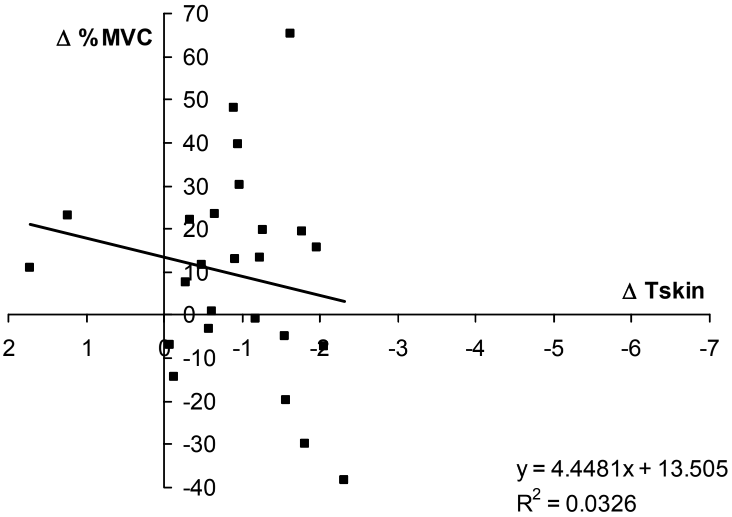


Figure 5 Change in muscle activity (Δ%MVC) under Gz as the function of the cooling of muscles (change of skin temperature: ΔTskin). R^2 = coefficient of determination. A.) Sternocleidomastoides (SCM); B.) Trapezoids (TRA)

5.3 Helmet, NVG and EMG on the trampoline (III)

When comparing bouncing without and with the helmet, the mean muscle strain (%MVC) during all exercises increased to a statistically significant extent in the

SCM, CES and TRA. The NVG device further increased strain in all muscles, but to a lesser extent. NVG induced change in strain was statistically significant in the SCM and CES (Table 5).

Table 5 The mean effect of the helmet and NVG on the muscle strain (%MVC) in all exercises combined.

	Baseline		Helmet				Helmet + NVG			
Muscle	%MVC	CI95%	%MVC	CI95%	ΔHEL (%)	p_{HEL}	%MVC	CI95%	ΔNVG (%)	p_{NVG}
SCM	14.4	12.2 to 16.6	16.8	14.0 to 19.6	18.0	0.002	18.2	15.1 to 21.3	11.2	0.006
CES	19.7	16.8 to 22.6	25.1	20.8 to 29.4	28.2	<0.001	26.2	21.6 to 30.8	5.9	0.043
TRA	16.7	12.7 to 18.9	18.6	14.2 to 23.0	18.1	0.002	18.5	14.2 to 22.8	4.7	0.485
TES	23.3	18.5 to 28.1	24.7	18.1 to 30.3	11.0	0.218	25.5	21.0 to 30.0	16.6	0.258

%MVC = proportional maximal voluntary contraction activity; ΔHEL = the mean of individual changes in %MVC (in percent) between baseline load and load with a helmet; ΔNVG = the mean of individual changes of %MVC (in percent) between load with a helmet and a helmet with NVG;; pHEL = the significance of difference in %MVC values between the baseline and helmet; pNVG = the significance of difference in %MVC values between the helmet and NVG
SCM = sternocleidomastoids; CES = cervical erector spinae; TRA = trapezoids; TES = thoracic erector spinae

Muscular loads during every exercise were also analysed separately (Table 6). During basic bouncing, helmet induced increase in muscle strain was statistically significant in the posterior muscles CES and TRA. The extra frontal mass due to NVG-device, increased strain mostly in the SCM and TES, but this increase was not statistically significant.

Back bouncing with a helmet increased strain in the cervical muscles, SCM and CES significantly. NVG increased loads to a statistically significant extent in the SCM.

Baseline muscle strain was the lowest in all measured muscles during extensor loading; i.e., hand and knee bouncing compared to other exercises. However, the helmet increased muscle strain in a statistically significant manner in all muscles except the TRA. NVG induced extra load was statistically significant in both the CES and TES.

Table 6 Muscle strain under different conditions.

	Basic Bouncing										
	Baseline		Helmet				Helmet + NVG				
Muscle	%MVC	CI95%	%MVC	CI95%	ΔHEL (%)	p_{HEL}	%MVC	CI95%	ΔNVG (%)	p_{NVG}
SCM	11.7	9.2 to 14.2	13.1	10.1 to 16.1	13.0	0.092	13.6	11.0 to 16.2	11.9	0.305
CES	19.6	15.3 to 23.9	22.9	18.1 to 27.7	18.7	0.005	22.4	18.3 to 26.5	1.6	0.325
TRA	25.1	16.2 to 34.0	28.0	18.4 to 37.6	12.0	0.010	27.0	18.4 to 36.2	3.6	0.359
TES	26.8	16.1 to 37.5	28.3	16.0 to 40.6	3.3	0.134	27.8	19.4 to 36.2	11.1	0.424
	Back Bouncing									
	Baseline		Helmet				Helmet + NVG			
Muscle	%MVC	CI95%	%MVC	CI95%	ΔHEL (%)	p_{HEL}	%MVC	CI95%	ΔNVG (%)	p_{NVG}
SCM	21.0	4.1	23.8	18.5 to 29.1	14.2	0.037	27.1	21.1 to 33.1	13.5	<0,001
CES	21.0	7.0	24.9	15.1 to 34.7	18.7	0.042	24.9	15.3 to 34.5	2.4	0.469
TRA	14.7	4.5	15.8	10.3 to 21.3	12.9	0.149	16.7	9.9. to 23.5	4.4	0.340
TES	25.9	7.9	23.7	13.9 to 33.5	-0.5	0.328	22.2	16.7 to 27.7	10.3	0.313
	Hand and Knee Bouncing									
	Baseline		Helmet				Helmet + NVG			
Muscle	%MVC	CI95%	%MVC	CI95%	ΔHEL (%)	p_{HEL}	%MVC	CI95%	ΔNVG (%)	p_{NVG}
SCM	10.8	1.9	14.1	9.7 to 18.5	26.6	0.039	14.6	10.5 to 18.7	8.5	0.305
CES	18.5	3.6	27.4	20.1 to 34.7	45.7	0.003	31.1	22.2 to 40.0	13.3	0.004
TRA	10.1	3.5	11.7	7.9 to 15.5	28.6	0.077	11.7	7.7. to 15.7	6.2	0.482
TES	17.5	5.5	22.0	15.1 to 28.9	28.5	0.025	26.9	18.0 to 35.8	27.5	0.025

%MVC = proportional maximal voluntary contraction activity; ΔHEL = the mean of individual changes in %MVC (in percent) between baseline load and a load with a helmet; ΔNVG = the mean of individual changes in %MVC (in percent) between load with a helmet and helmet with NVG; p_{HEL} = the significance of difference of %MVC values between baseline and helmet; p_{NVG} = the significance of difference of %MVC values between helmet and NVG

SCM = sternocleidomastoids; CES = cervical erector spinae; TRA = trapezoids; TES = thoracic erector spinae.

5.4 Lumbar support under high Gz (IV)

The comparison of +Gz loads during the test flights are shown in Figure 6. There were no differences (p=0.34) in +Gz load between flight with and without the lumbar support.

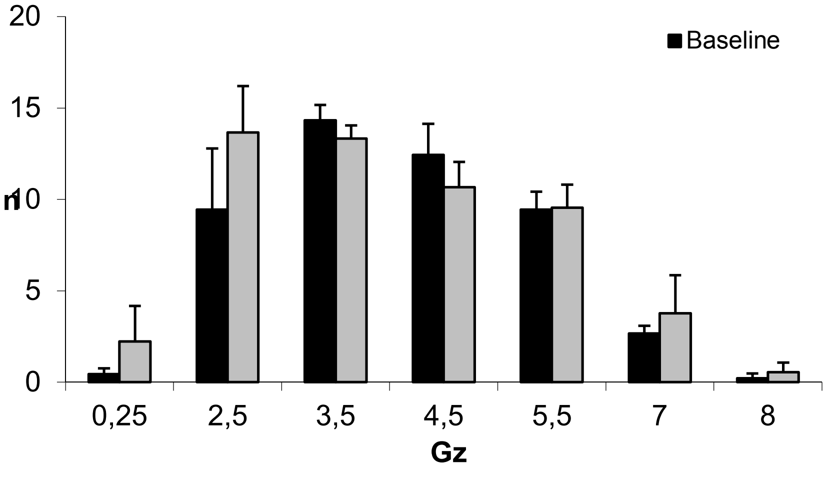


Figure 6 Gz loads during the test flights. The aircraft's accelerometer recorded the number of times the given Gs were exceeded

In all measured muscles, the mean %MVC was lower when a lumbar support was used. Individual differences in %MVC between the flights reduced in the cervical, thoracic, and lumbar erector spinae muscles (Table 7). The interindividual deviation was wide, however, and the change in muscle activity (EMG) was not statistically significant in any measured muscle. As seen in Figure 7, some subjects benefited from the support, while others experienced an opposite effect, at least in some muscles.

Table 7 Muscle activity (EMG) with and without a lumbar support

	Baseline		Lumbar support		Change (%)		
Muscle	%MVC	CI95%	%MVC	CI95%	Δ %MVC	CI95%	p
SCM	24.3	17.1 to 31.5	23.9	17.0 to 30.8	4.0	-19.7 to 27.7	0.844
CES	39.2	23.1 to 55.3	36.8	25.4 to 48.2	-9.3	-20.6 to 2.0	0.493
TES	24.7	18.7 to 30.7	24.1	16.7 to 31.5	-7.2	-25.8 to 11.4	0.771
LES	22.1	16.9 to 27.3	20.2	14.4 to 27.0	-7.5	-31.4 to 16.4	0.367

%MVC = proportional maximal voluntary contraction activity; Δ %MVC = the mean of individual changes in %MVC (in percent) between the test flights
SCM = sternocleidomastoides; CES = cervical erector spinae; TES = thoracic erector spinae; LES = lumbar erector spinae.

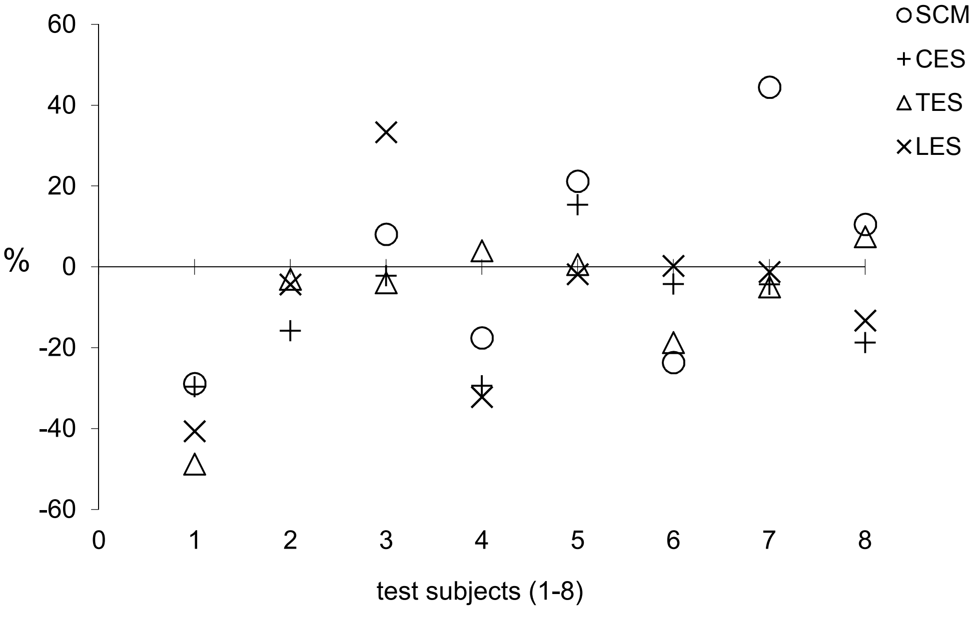


Figure 7 Change in measured muscle activity (EMG) during test flights with a lumbar support. Flight without a support was the baseline (0%). SCM = sternocleidomastoids; CES = cervical erector spinae; TES = thoracic erector spinae; LES = lumbar erector spinae.

There was also a tendency towards the increased number of EMG gaps when flying with a lumbar support (Table 8). The change was negative only in the CES. The duration of the gaps was shortened by 19% (CI95%: 6 to 32%;

p=0.004) in the SCM with a support, otherwise there was no change in gap duration.

Table 8 The number of EMG gaps and their changes during flights. Flight without a support is the baseline.

	Baseline		Lumbar support		Change (%)		
Muscle	Gaps/min	CI95%	Gaps/min	CI95%	Δ Gaps	CI95%	p
SCM	31.6	21.4 to 41.8	32.9	23.2 to 42.6	13.1	-25.4 to 51.6	0.761
CES	39.5	23.5 to 55.5	38.5	28.1 to 48.9	- 3.5	-28.4 to 21.4	0.802
TES	44.6	32.0 to 57.2	43.9	31.4 to 56.4	18.7	-61.5 to 98.9	0.850
LES	44.6	29.8 to 59.4	48.1	31.2 to 65.0	14.5	-16.6 to 45.6	0.421

Δ Gaps = the mean of individual changes in the rate of EMG gaps (in percent) between the test flights

SCM = sternocleidomastoids; CES = cervical erector spinae; TES = thoracic erector spinae; LES = lumbar erector spinae.

Five subjects stated that the support improved sitting comfort, five noticed no changes, and one reported reduced comfort from normal i.e. baseline flight without a lumbar support. No displacements of the support were reported. Musculoskeletal symptoms during flights with a support reduced by 25% (CI95% 14 to 36%, p=0.002) according to visual analogue scale (VAS) responses. One subject reported less fatigue in the neck muscles, while three subjects reported a less fatigued lower back when flying with a support. Fatigue experienced by the subjects as quantified by the VAS reduced by 3% (CI95%: 0 to 6%, p=0.14) in the neck muscles, and by 10% (CI95%: 1 to 19%, p=0.67) in the lower back. Reported symptoms or fatigue during flights did not correlate with measured muscle strain (%MVC) or EMG gaps.

5.5 Training interventions and in-flight muscle strain (V)

The comparisons of +Gz-loading during the test flights is shown in Figure 8. +Gz-loads were similar between the training groups (p=0.21) and between flights in the beginning and upon completion of training period (p=0.23).

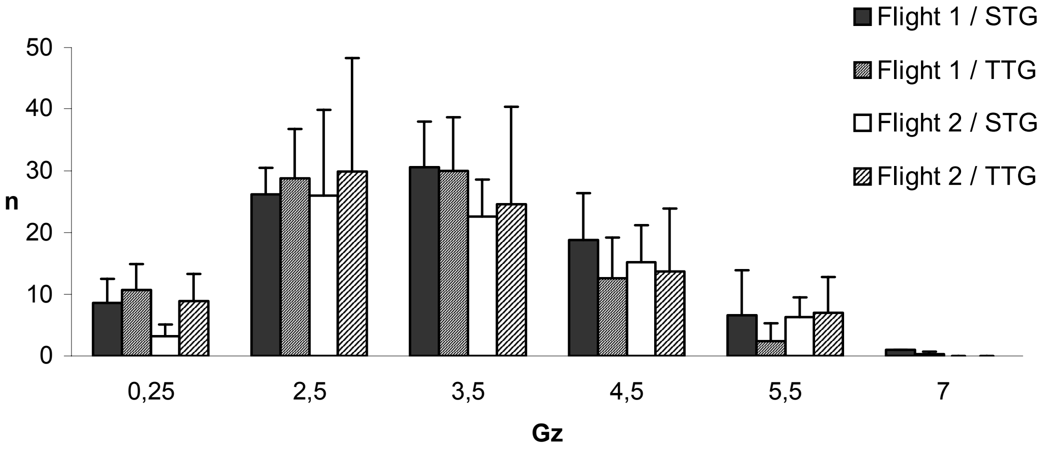


Figure 8 +Gz-loads during test flights. The aircraft's accelerometer recorded the number of times the given Gs were exceeded during the flight.
Flight 1 = baseline, Flight 2 = post intervention
STG = strength training group, TTG = trampoline training group

Maximal muscle force increased in both groups in all measured directions after the training period. Improvement in flexion force was significantly better in the TTG; otherwise, no statistically significant differences between training groups were noted. (Table 9)

Table 9 The effect of training period on maximal forces.

Cervical force	STG			TTG			Pre- vs. Post-test	STG vs. TTG
	Pre-test (N)	Change (%)	CI (95%)	Pre-test (N)	Change (%)	CI (95%)	p	p
Flexion	316	+ 2.3	1.8 to 2.8	337	+ 3.2	2.9 to 3.5	<0.001	0.005
Extension	155	+ 6.0	5.4 to 6.6	200	+ 6.4	5.9 to 6.9	<0.001	0.250
Rotation	160	+ 6.5	-0.2 to 12.5	176	+ 3.1	-2.5 to 8.7	0.052	0.423

In-flight muscle strain (%MVC) reduced after training period in both groups, most markedly in the cervical muscles, and especially in the SCM. The effects of training were not so apparent in the TRA and TES. There was no statistically significant difference in in-flight muscle strain between the groups (Table 10).

Table 10 The effect of training on muscle activity (EMG) during test flights described as changes in %MVC.

	STG		TTG		Flight 1 vs. Flight 2	STG vs. TTG
Muscles	Δ %MVC	CI (95%)	Δ %MVC	CI (95%)	p	p
SCM	-34.5	-63.9 to -5.2	-12.5	-52.6 to 27.6	0.049	0.637
CES	-2.6	-15.2 to 10.7	-29.2	-43.9 to -14.7	0.053	0.080
TRA	4.5	-23.3 to 32.3	6.4	-18.0 to 30.8	0.428	0.675
TES	12.8	8.3 to 17.2	-7.2	-41.5 to 27.1	0.933	0.637

CLT measurements showed similar results. Both training methods reduced muscle strain in cervical muscles, both in the SCM and in CES. No apparent difference was noted in the lower muscles. Again, there was no statistically significant difference in any measured muscle between the groups (Table 11).

Table 11 The effect of training on muscle activity (EMG) in the Cervical Loading Test (CLT) described as changes on %MVC

	STG		TTG		Pretest vs. Post-test	STG vs. TTG
Muscles	Δ%MVC	CI (95%)	Δ %MVC	CI (95%)	p	p
SCM	-17.3	-32.5 to -2.1	-6.7	-23.2 to 9,7	0.059	0.291
CES	-15.7	-24.3 to -7.2	-22.0	-33.1 to -10.8	0.001	0.555
TRA	-30.0	-65.8 to 5.9	-9.5	-31.7 to 12.7	0.347	0.688
TES	-23.7	-43.6 to -3.7	-26.4	-40.1 to -12.9	0.013	0.582

5.5.1 The sustainability of the results

There was a tendency towards reduced EMG activity during the CLT in all muscles from the beginning till the end of the follow-up (Figure 9). The positive effects of training on muscle loading were sustained in the cervical area in both training groups (STG and TTG), yet no similarly clear results were observed in the TES. No statistically significant difference between the groups was noted.

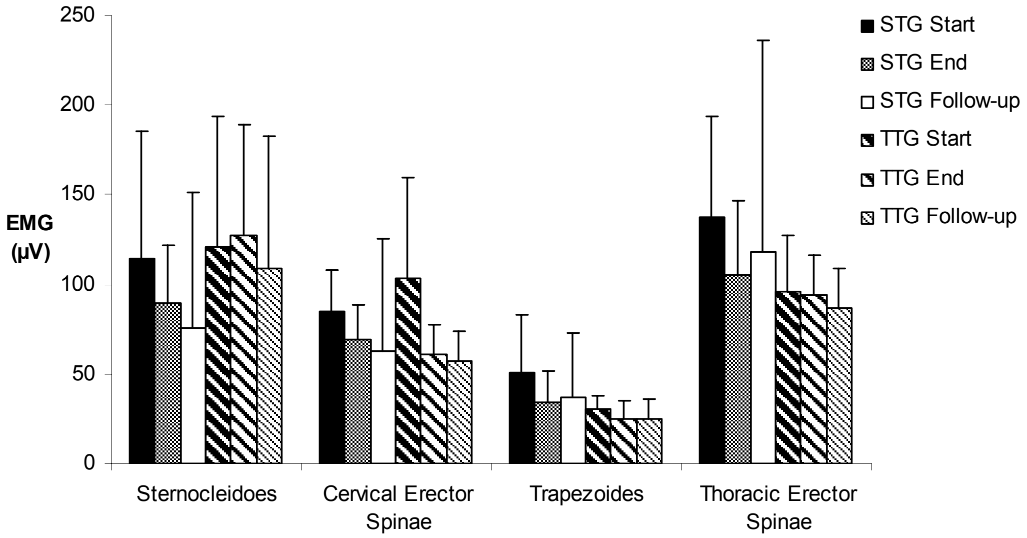


Figure 9 EMG activity during the CLT in all muscles at the beginning (pre-test) and upon completion of training period (post-test) and after three months (Follow-up).
STG = Strength training group, TTG = Trampoline training group

6 Discussion

6.1 Degenerative changes in cervical spine radiographs (I)

According to literature, Gz loads cause premature degenerative changes, particularly in the cervical spine. However, the longitudinal study (I) produced few and minor findings and showed that exposures to high Gz during over 1200 flying hours caused no significant radiological changes in the spinal column, especially in its cervical part, during the subjects' active flying career, which is contrary to other studies (Hendriksen and Holewijn 1999; Hämäläinen et al. 1993b). The comparison of the changes with the controls did not show any statistical difference between groups.

Since technical advances took place during the relatively long follow-up period, the baseline and follow-up images were obtained using different imaging systems, and, the equal rating of different quality images was therefore challenging. Two protrusions in baseline cervical MRI were not seen in the follow-up images. All other changes rated at the baseline were re-rated in the follow-up images, and this was considered to confirm the reliability of the evaluation of images. Nevertheless, the aim was to provide reliable and comparable evaluations between the baseline and follow-up images with simple grading, and only clearly apparent and significant changes were taken into consideration during the evaluation of the images. The development of the stenosis of the spinal column was not evaluated in this study due to the lack of accurate evaluation method in between both the baseline and follow-up images. Since it is suggested that Gz-exposure could cause degenerative spinal stenosis of the cervical spine (Hämäläinen et al. 1999). Thus, it might be of value to follow up stenotic changes in further studies and during pilots' periodical medical examinations.

The scope of the study was more occupational than radiological, so the grading of findings was set to be simpler and more forthright than suggested recently (Kolstad et al. 2005). However, since a simple grading system in evaluation sacrifices variations in documentation, more definite grading with probable greater variation in results would appear to yield statistically more significant results. In addition, the small sample size may have had an effect on the statistical significance of the analysis.

Grading was based on morphological changes in hard tissues; degenerative disk changes and injuries as well as osseous formation. Radiologically muscle and ligament injuries and findings are usually acute problems in nature. As the follow-up study focused on the long term effects of Gz-exposure, these soft tissue findings were not graded and evaluated. According to the theory of cumulative trauma, these probable soft tissue injuries also lead to degenerative changes in hard tissues, but it has not been determined when these subsequent changes take place. They may still appear later, even after a long follow-up.

However, a minor difference in the location of changes in the cervical spine was noted between the groups, which is in accordance with the earlier reports.

Lower discs and vertebras carry the cumulative loads of the upper structure. There again, the greatest ROM in flexion-extension is in C5-6, and the greatest ROM in all planes is in the segments above that. It has been suggested that high Gz related injuries occur most likely in these segments. The theory of cumulative trauma suggests that acute soft tissue injuries lead to degenerative changes, and this may take place in the lower segments due to the reduced movements and their control of the segments above. Alternatively, in the lumbar spine degenerative changes seems to be more associated with age rather than just with Gz-exposure (Aydog et al. 2004; Hendriksen and Holewijn 1999; Landau et al. 2006; Petren-Mallmin and Linder 2001).

Certain factors combined may have contributed that degenerative changes are not developing as prematurely as reported earlier. The awareness of spinal injuries and degenerative changes has arisen during the past decade. Since the baseline images were taken in 1993-1994, pilots have perhaps discussed their symptoms with physicians more openly, which has resulted in earlier diagnosis and treatment. In addition, physical conditioning programs have been developed and directed to pilots, and head support strategies have been taught and implemented more than before. Lighter helmets may also have a positive effect (Hämäläinen 1993b), even though this advantage is being lost, at least partially, due to HMDs (Newman 2002; Phillips and Petrofsky 1983a; Thuresson et al. 2003).

It has to be born in mind that all symptomatic lesions have individual and occupational significance regardless of the type of degenerative changes. As it seems that imaging cannot provide evidence of the long-term effects of Gz-exposure, other methods need to be addressed to follow-up the musculoskeletal effects of Gz loading. Assessments for the need of follow-up imaging should be based on clinical outcome, not on periodical imaging. It is very important to combine radiological findings with symptoms data as well as with biomechanical measurements and physical activity and fitness, especially of the cervical musculature. Clinical examination including the range of cervical movements, isometric strength and carefully documented musculoskeletal and neurological symptoms could give additional information to support imaging. This way, both clinical survival and occupational performance could be determined and assessed optimally. Yet it is possible that some degenerative effects of Gz will appear years later and further follow-up is therefore recommended.

6.2 Factors contributing to cervical loading (II, III)

As the radiological study showed only minor changes, and led to no major findings or determinants longitudinally, it is exceedingly important to look at acute soft tissue responses, i.e. muscular loads under Gz.

The determinants considered seem to have an increasing effect on loads on the cervical muscles. Both cold exposure and the extra mass of a helmet system increase cervical muscle strain under Gz. Pre-flight warm-up is therefore recommended as a mandatory routine, and it is considered important to prevent the cooling of the muscles in a cold environment. A neck-covering balaclava under the helmet is recommended during wintertime. Since developments in aircraft performance and flying gear add to cervical loading, better muscle conditioning programmes, enhanced muscle coordination and head support strategies are needed to prevent neck injuries stemming from the extra mass of a helmet.

6.2.1 Cold, Gz and muscle strain (II)

Cold exposure during pre-flight checks was significant already in moderate winter conditions. Skin temperature decreased significantly over the trapezoid muscles underneath the flight suit, jacket and harnesses.

Measurements were taken in moderate winter conditions during training sorties with the Hawk. Pilots in high latitudes often need to work in ambient temperatures of under -25°C. Time for pre-flight checks before start-up and yet again time to take-off may be even longer in fighter operations, as there is more switchology to do in a modern cockpit. This prolonged time spent in a cold cockpit will naturally lengthen cold exposure and resultant cooling of the skin and muscles. Once airborne, the cockpit starts to warm up and cooling stops. The longer a transit flight, the longer is the time for pilot's muscles to warm up again before high-Gz maneuvering begins, and vice versa. The whole magnitude and significance of this phenomenon may result in a smaller gap between the maximal muscle capacity and muscle capacity needed under high Gz.

The detrimental effect of low temperature exposure to the skin and muscle temperature and the resultant reduction of muscular performance are widely documented and well known. This study is the first one to document reduction in skin temperatures, which most likely is also indicative of muscular cooling, and resulting greater muscle strain observed under Gz. Cooling in a cold environment produced increased muscle strain under Gz in neck area. However, cooling-induced changes in muscle strain were variable and statistically insignificant. A careful approach should be taken towards figures presented in the results and it should be understood that they indicate the magnitude of the phenomenon and are not constant values. The phenomenon remains to be discussed, but pre-flight cooling effect may have significance in terms of more frequent cervical disorders among fighter pilots who are exposed to cold winter conditions more frequently.

6.2.2 Helmet, NVG and EMG on a trampoline (III)

Lighter helmets have been developed to reduce the cervical loads under Gz. Our study (III) indicates that heavier helmets have a more significant effect on cervical muscle loading (than the lighter mass of NVG, with a shift in the centre of gravity of the head-helmet complex). This reflects the significance of mass during acceleration and under inertia forces.

Based on muscle strain levels (%MVC) observed during trampoline exercises, NVG seem to increase the total workload most in the cervical muscles SCM and CES. This may be due to the nature of the trampoline exercises that load the flexor and extensor muscles (back bouncing and hand and knee bouncing) in particular. Rapid acceleration onset rates encountered during these exercises may also cause some extra activity in the cervical muscles as the subject strives to maintain head stability. In addition, cervical extensor strain is above flexor strain during exercises. The extensor muscles are stronger than the flexors (Garces et al. 2002; Seng et al. 2002), so their activity levels should be lower under somewhat constant acceleration forces, but some factors may affect the results and are discussed below.

Higher activity levels in TRA and TES during basic bouncing may indicate that basic bouncing also loads considerably the thoracic muscles. Although the head was maintained in the neutral position during the exercises, and the direction of loads was basically along the x-axis during back bouncing and hand and knee bouncing, muscle activation, not the actual direction of the loads, was considered important in this case.

However, some controversy with regard to the effects of altered CG is presented widely in literature. In study III, NVG appear to affect essentially those muscles already subjected to the highest load and seem to increase the total workload most in the cervical muscles SCM and CES. Even though activity levels were not critical, strain in the loaded muscles in particular increased significantly, which may reflect the complex neuromuscular control system of the head and neck.

De facto, the limited field of vision allowed by NVG results in increased head movements when the pilot needs to scan the airspace for target acquisition. However, Gz loads are usually moderate when flying at night with NVG. A greater risk are modern helmet mounted sighting systems, which like NVG, add the mass of a helmet and shift its CG in a more upward and frontal direction. When a pilot is trying to get a lock on a maneuvering target with a cueing system he/she may need to apply higher Gz, have the head for extended time in a non-neutral position, and move the head under Gz more than when flying without HMD. This increased load combined to head movements while wearing a heavier helmet with the CG shifted means a severe risk of cervical injury. This situation is completely opposite to recommendations for lighter helmets and less movements.

6.3 Factors reducing cervical loading (IV, V)

This study hypothesised that Gz-induced neuromuscular strain could be reduced by improving the sitting posture with a lumbar support and/or by improving muscular capacity and performance through training. Additionally, the trampoline was introduced as a training method for fighter pilots. Both these measures seem to have some diminishing effects on muscle strain. However, it is recommended that the suitability and effectiveness of a lumbar support be tested for pilots suffering in-flight spinal symptoms. It is essential that a flight surgeon assess the need and benefits of a support individually.

Pilots' physical education programmes should be developed to meet occupational challenges. Specific neck muscle conditioning facilities should be set up in squadrons and their use should be supported by training programmes designed to activate pilots to maintain and improve neck muscle strength and co-ordination. Similarly, wide inter-individual deviations in measured responses during training intervention may reflect a need for individually assessed programmes.

6.3.1 A lumbar support under high Gz (IV)

The subjects' subjective experiences were predominantly positive after flights with a lumbar support since most of them felt that the support relieved symptoms and alleviated fatigue. However, the support needs to be carefully adjusted. If a pilot has no history of earlier flying-related back or neck problems, the support may then produce symptoms or have an adverse effect on muscle strain.

This study indicated that there seems to be a tendency towards a lower muscle strain when a support is worn. Muscle strain decreased in all measured erector spinae muscles in the cervical, thoracic, and lumbar region, but the changes were not statistically significant. A reduced sample size may also have affected statistical evaluation of results since the muscular in-flight activity of only eight subjects could be recorded accurately.

There was a tendency towards a slight increase in the number of EMG gaps when a lumbar support was worn. The duration of these gaps did not change significantly, only the gaps in the SCM were shorter, but conversely it seemed likely that the number of gaps in the SCM increases when a support is worn. The measurements obtained showed a wide inter-individual variation in all muscles, however. Reports claim that the presence of EMG gaps is related to a reduced loading effect on muscles; and vice versa, lack of gaps likely leads to a higher incidence of symptoms (Sjogaard and Sogaard 1998; Veiersted et al. 1993).

This study was conducted with experienced pilots, and since measurements were performed only during one flight with lumbar support, some disturbance in neuromuscular adaptation may have occurred during a test flight compared to the normal status. A longer test period could have reduced these deviations. The questionnaire was repeated to the pilots after a three-month follow-up, but results obtained did show any significant change.

It is therefore suggested that some individuals may benefit from the support greatly owing to decreased muscular loading that it brings along, yet others may experience opposite effects. The assessment of a lumbar support needs to be done with care. Although this study does not indicate that a support would prevent back or neck symptoms in pilot population, it may help individuals who have some back or neck problems and whose sitting ergonomics need to be improved.

6.3.2 Training interventions and in-flight muscle strain (V)

This study (V) showed a small but statistically significant improvement in the maximal muscle force in both training groups. Increased neuromuscular performance and intermuscular coordination may increase mechanical efficiency in maintaining cervical stability and thus have a beneficial effect under loading force.

Training was most effective in the cervical area (SCM and CES), but positive effect was also seen in the lower muscles (TRA and TES) which may partly be due to the exercises conducted. The strength training programme (STG) mainly consisted of exercises that activated the cervical muscles, while the trampoline training group (TTG) performed exercises that load especially cervical flexors and extensors. Despite of the fact that training period was relatively short and both training programmes consisted of low-intensity submaximal loading, all subjects showed an increase in flexion and extension forces. It has also been reported in the literature that submaximal strength training or endurance training has a positive effect on the maximal strength (Bell et al. 1991; Braith et al. 1993; Izquierdo et al. 2003).

It is likely that training (STG and TTG) enhanced the submaximal endurance and motor coordination of the cervical muscles. Training may cause adaptations to many neural elements involved in the control of movements. Increased neuromuscular performance and intermuscular coordination may increase mechanical efficiency in maintaining cervical stability and thus have a beneficial effect in decreasing in-flight and CLT muscle strain.

In combination with resistance training, proprioceptive training has reported to achieve higher cervical muscle hypertrophy in general and the effect on cervical motor control capability is not deteriorating as compared to isolated resistance training (Kramer et al. 2013). It may be assumed that strength training would enhance more submaximal endurance and trampoline training would improve motor coordination than vice versa. Yet, based on the results of this study, this remains speculation. But if speculated still further, different training methods may expand the capacity of muscles in a variety of ways, which may in turn produce even more beneficial changes when they are combined in a training programme.

Similar change in muscle strain was seen in the CLT as during in-flight EMG-measurements. This supports the hypothesis that improved muscular capacity due to training reduces muscle strain under Gz. The test also excluded the effects of the cadets' improved flying skills during training period as a factor to change in muscular strain. Improved flying skills or learning had no effect on the loading in the CLT. %MVC levels were higher in the CLT than during flights, which may be due to more impulsive and impact type loads as opposed to moderate, more sustained in-flight accelerations. The sorties flown involved basic aerobatics and single-ship maneuvers. This may reflect in-flight %MVC levels that were not very high, unlike some other reports (Green and Brown 2004; Hämäläinen 1993b; Le Menn et al. 1995; Oksa et al. 1996).

Trampoline training may have a positive effect from the occupational standpoint since it loads the cervical muscles in a way somewhat similar to in-flight Gz, and it is therefore assumed to develop neuromuscular function beneficially. The level of muscle activation recorded from the neck flexors and extensors in this study was comparable with in-flight measurements obtained in previous studies.

However, any comparison of different in-flight and test pattern results needs to be undertaken with care. The trampoline induces impact type loads of +4Gz, which are very different from sustained in-flight Gz forces. The onset rate of Gz loading on a trampoline is around 10 to 12 G/s, which fairly well corresponds to onset rates produced by modern high performance fighters. The trampoline may have a potential for the training of the cervical muscles with the aim of maintaining the posture of the head during that important first second of Gz. Non-axial loads occurring during some trampoline exercises have to be considered as a limitation of a method. When the neck area flexors or extensors are loaded in particular, the spine is perpendicular to load, i.e. inertial acceleration force is applied in the direction of the Gx-axis. In this method head stabilisation during impact simulates head movement or a non-neutral head position, where subjected muscles are loaded. However, despite this discrepancy with force vectors, training seems to improve in-flight muscular performance.

6.3.3 *The sustainability of the results*

Upon completion of the three-month follow-up, the electrical activities of the muscles during the CLT were similar to those observed after the training period. During the follow-up period, the subjects did not perform any improving or even sustaining exercises. A strenuous air combat training period was in full swing, and their physical activity after work was minimal, consisting of recovering-type muscle maintenance. Reduced muscle strain in the cervical muscles was still seen compared to the baseline. There was no statistically significant difference between training methods.

It can be argued that high-Gz flying would improve cervical muscle strength itself. However, the studies on the effects of in-flight loads have been unable to present positive effects on muscular performance with other test modalities (Burnett et al. 2004; Seng et al. 2003). It is therefore considered that flying during the follow-up period has no effect on results measured in the CLT.

Äng (2007) reported that supervised neck/shoulder exercise intervention had a positive preventive effect in reducing neck pain cases among helicopter pilots over a 12-month follow-up period. Otherwise, there is a lack of studies to prove the long-term effects of certain interventions. Conversely, the low-intensity activation of muscles or immobilisation leads to a decrease in the cross sectional area of muscles and degraded performance. On the other hand, some reviews suggest that muscle conditioning has positive long-term effects in terms of preventing musculoskeletal disorders. However, there is no evidence of its efficacy for acute back pain (Linton and van Tulder 2001; Schonstein et al. 2003).

7 Conclusions

The present study, evaluated some specific effects on fighter pilots' musculoskeletal loading. The conclusions to be drawn are:

- High-Gz exposures encountered during over 1200 hours flying time did not cause significant radiological changes in the spinal column
- Pre-flight cooling effect may have significance in terms of more frequent cervical disorders among fighter pilots who are exposed to cold winter conditions more frequently
- The cooling of muscles may lead to a smaller gap between the maximal muscle capacity and muscle capacity needed under high Gz
- Helmet weight seems to induce more muscle strain than NVG, but helmet-mounted devices also have a significant effect on increased cervical loading
- There seems to be a tendency toward a lower muscle strain when a lumbar support is worn, but there are considerable individual differences
- Both cervical strength training and trampoline exercises have a positive, reducing effect on the neck muscles strain under in-flight Gz

The risk factors considered increase pilots' musculoskeletal loads under high Gz, and add to the risk of cervical disorders. Figure 10 presents the synthesis of the results of this study. The mass of helmet and use of helmet-mounted devices emerge as potential factors to increase muscle strain. This risk can be alleviated in part by improving pilots' muscular performance, and in certain cases, by improving sitting ergonomics with an individual lumbar support.

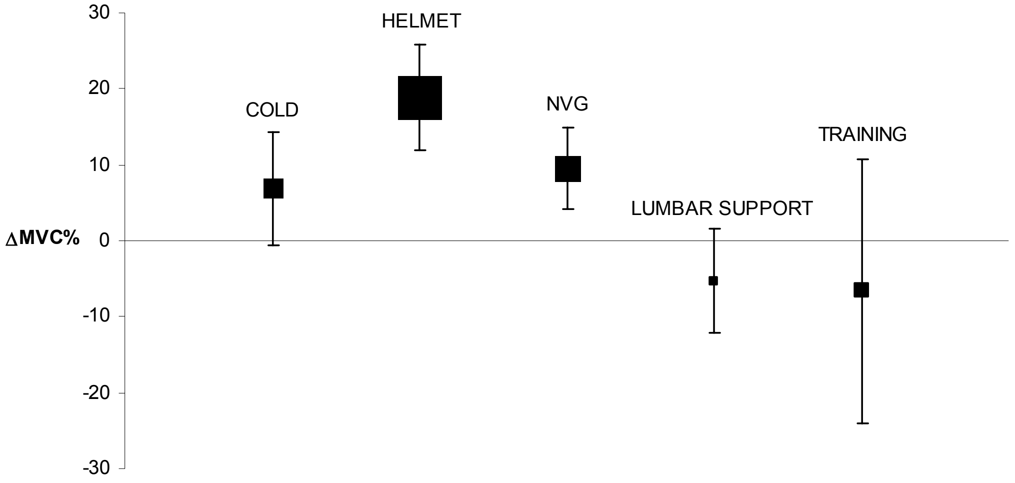


Figure 10 The synthesis of the results of muscular loads in the this study.
The mean values of the changes in MVC% with confidence intervals are presented.

Acknowledgements

"A man's got to do, what a man's got to do"
–John Wayne, and some others, too

However, few people have contributed this study and I would like to acknowledge some of them.

As a graduating medical student I asked from former Chef Flight Surgeon of Finnish Air Force colonel (MC) Pentti Kuronen where and what kind of work should I do to get also into the field of aeromedical world. His answer was that you must be a flight surgeon, and that he has a job for me at Air Force Academy, Kauhava. The offer included ten things to thank; this doctoral thesis project among them. To retired Major General Pentti Kuronen I am grateful to taking me in and pushing me into the right(?) direction. Within his footsteps continuous developing of aeromedical issues has been easy to follow.

Major (MC) Simo Siitonen, who followed Pentti Kuronen's path, was Chef Flight Surgeon at the time I was writing the articles of this study and this dissertation (sic!). He gave me guidance and restrictions with my work. His constructive comments improved my texts and helped to keep on the focus. The aim of our studies has been and will be to improve our actions pro volantibus, and Brigadier (MC) Simo Siitonen taught this to me.

From early days of this study docent Juha Oksa has been my co-worker and consultant. Within his guidance the problems and challenges has defeated. Work has always made with lots of loughs despite of serious-taking-academic-problem-solving discussions. My mentor, my supervisor, I salute you!

Despite of Juha's superior supervising something more was required to reach the goal. Most of this study has been done in the fields of Kauhava, surrounded by the gates of base, and some universitial and academic vision and guidance was needed. Prof. Markku Järvinen suited perfectly to this assignment. His guidance has been precious and his ass-kicking role during last years of too-long finishing phase of this study has been invaluable. This book owes you, Sir!

"This is good, but I made some corrections." Tapio Kakko helped me to improve the texts of my publications without saving his time or red pen and without giving up the pedagogic point of view in his feedback. All my readers appreciate these contributions. My clumsy words are not enough to tell how much I valued his support.

M.Sc. Heini Huhtala guided, supported and challenged me with statistical analyses during the project and beyond. You saved me, and these lines are far too short to express my gratitude. But I'll be back. To be saved.

Then I must recognize my brother-in-arms, PhD Harri Rintala. Literary with blood, smear and tears two men have pushed through with their vision of pilots fit to fly. The more intolerable challenge we faced, the more imaginative was the solution. And sometimes some guidance was needed, as stated bit earlier. Two men portable test lab was moved where needed (our opinion) repeatedly and the fame started to go before us. A few air force pilots have evaluated and a few stories are to be told. It has been a pleasure and privilege to work with you, and we will go on from our new dugouts.

Then I would like to thank Mrs Rintala, too. PhD, M.D. Pirjo Rintala was even messed to our work, but above all, I thank her of her supportive words when they were needed. And they were.

When speaking about support, I must also acknowledge Urho Council and their friendly support that has stood by during the course of these years.

I would like to mention also my personnel in garrison's health station at Kauhava. Your support, your patience and your help gave me an opportunity to perform these studies. I am pleased to have an opportunity to work with you and I wish my best luck to you in future.

Naturally, this work would have not been done without contributions of personnel, instructors and cadets of Training Air Wing. You were always in line of fire when something needed to measure and you were willing to help and co-operate. My warmest thanks go especially to wing commanders Pali Rantamäki and Jussi Virtanen due to their efforts in arrangements of measuring events and test flights. Although, my experiments did not include measurements Pali requested.

Finally, I need to make an apology to my wife and children that I have done this. Quoted phrase above gives the best, but just a pale explanation why this has been done. All I have asked is to be alone every now and then, take care of everything, to be flexible where I couldn't, to tolerate sleepless man, to understand everything even though I have not explained at all, and bear some missed moments of our lives. All I got was patience, flexibility, endurance, understanding and supportive home with love. I try to be worth of you.

Literature

Abdulkarim, J. A., Dhingsa, R., DB, L. F. (2003). Magnetic resonance imaging of the cervical spine: frequency of degenerative changes in the intervertebral disc with relation to age. *Clin Radiol, 58*(12), 980-984.

Alricsson, M., Harms-Ringdahl, K., Larsson, B., Linder, J., Werner, S. (2004). Neck muscle strength and endurance in fighter pilots: effects of a supervised training program. *Aviat Space Environ Med, 75*(1), 23-28.

Andersen, H. T. (1988). Neck injury sustained during exposure to high-G forces in the F16B. *Aviat Space Environ Med, 59*(4), 356-358.

Andersen, H. T., Wagstaff, A. S., Sverdrup, H. U. (1991). Spinal X-ray screening of high performance fighter pilots. *Aviat Space Environ Med, 62*(12), 1171-1173.

Andersson, G. B., Murphy, R. W., Ortengren, R., Nachemson, A. L. (1979). The influence of backrest inclination and lumbar support on lumbar lordosis. *Spine, 4*(1), 52-58.

Aprill, C., Bogduk, N. (1992). High-intensity zone: a diagnostic sign of painful lumbar disc on magnetic resonance imaging. *British Journal of Radiology, 65*(773), 361-369.

Ashrafiuon, H., Alem, N. M., McEntire, B. J. (1997). Effects of weight and center of gravity location of head-supported devices on neck loading. *Aviat Space Environ Med, 68*(10), 915-922.

Aydog, S. T., Turbedar, E., Demirel, A. H., Tetik, O., Akin, A., Doral, M. N. (2004). Cervical and lumbar spinal changes diagnosed in four-view radiographs of 732 military pilots. *Aviat Space Environ Med, 75*(2), 154-157.

Beattie, P. F., Meyers, S. P., Stratford, P., Millard, R. W., Hollenberg, G. M. (2000). Associations between patient report of symptoms and anatomic impairment visible on lumbar magnetic resonance imaging. *Spine, 25*(7), 819-828.

Bell, G. J., Petersen, S. R., Wessel, J., Bagnall, K., Quinney, H. A. (1991). Physiological adaptations to concurrent endurance training and low velocity resistance training. *Int J Sports Med, 12*(4), 384-390.

Bergmark, A. (1989). Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthop Scand Suppl, 230*, 1-54.

Bertram, M. F., Nishida, T., Minieka, M. M., Janssen, I., Levy, C. E. (1995). Effects of temperature on motor unit action potentials during isometric contraction. *Muscle Nerve, 18*(12), 1443-1446.

Bigland-Ritchie, B., Thomas, C. K., Rice, C. L., Howarth, J. V., Woods, J. J. (1992). Muscle temperature, contractile speed, and motoneuron firing rates during human voluntary contractions. *J Appl Physiol, 73*(6), 2457-2461.

Boden, S. D., Davis, D. O., Dina, T. S., Patronas, N. J., Wiesel, S. W. (1990a). Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. *J Bone Joint Surg Am, 72*(3), 403-408.

Boden, S. D., McCowin, P. R., Davis, D. O., Dina, T. S., Mark, A. S., Wiesel, S. (1990b). Abnormal magnetic-resonance scans of the cervical spine in asymptomatic subjects. A prospective investigation. *J Bone Joint Surg Am, 72*(8), 1178-1184.

Braith, R. W., Graves, J. E., Leggett, S. H., Pollock, M. L. (1993). Effect of training on the relationship between maximal and submaximal strength. *Med Sci Sports Exerc, 25*(1), 132-138.

Buhrman, J. R., Perry, C. E. (1994). Human and manikin head/neck response to +Gz acceleration when encumbered by helmets of various weights. *Aviat Space Environ Med, 65*(12), 1086-1090.

Burnett, A. F., Green, J., Netto, K., Rodrigues, J. (2006). Examination of EMG normalisation methods for the study of the posterior and posterolateral neck muscles in healthy controls. *J Electromyogr Kinesiol.*

Burnett, A. F., Naumann, F. L., Burton, E. J. (2004). Flight-training effect on the cervical muscle isometric strength of trainee pilots. *Aviat Space Environ Med, 75*(7), 611-615.

Burnett, A. F., Naumann, F. L., Price, R. S., Sanders, R. H. (2005). A comparison of training methods to increase neck muscle strength. *Work, 25*(3), 205-210.

Burton, R. (1999). *Cervical spinal injury from repeated exposures to sustained acceleration.* (No. NATO RTO-TR-4). Neuilly-sur-Seine, Cedex, France.

Chen, J. C., Dennerlein, J. T., Chang, C. C., Chang, W. R., Christiani, D. C. (2005). Seat inclination, use of lumbar support and low-back pain of taxi drivers. *Scandinavian Journal of Work, Environment & Health, 31*(4), 258-265.

Clark, J. B. (1990). Cervical dystonia following exposure to high-G forces. *Aviat Space Environ Med, 61*(10), 935-937.

Coakwell, M. R., Bloswick, D. S., Moser, R., Jr. (2004). High-risk head and neck movements at high G and interventions to reduce associated neck injury. *Aviat Space Environ Med, 75*(1), 68-80.

Conley, M. S., Meyer, R. A., Bloomberg, J. J., Feeback, D. L., Dudley, G. A. (1995). Noninvasive analysis of human neck muscle function. *Spine, 20*(23), 2505-2512.

Conley, M. S., Stone, M. H., Nimmons, M., Dudley, G. A. (1997). Specificity of resistance training responses in neck muscle size and strength. *Eur J Appl Physiol Occup Physiol, 75*(5), 443-448.

Cunningham, L. K., Docherty, S., Tyler, A. W. (2010). Prevalence of low back pain (LBP) in rotary wing aviation pilots. *Aviat Space Environ Med, 81*(8), 774-778.

De Loose, V., Van den Oord, M., Burnotte, F., Van Tiggelen, D., Stevens, V., Cagnie, B. et al. (2008). Individual, work-, and flight-related issues in F-16 pilots reporting neck pain. *Aviat Space Environ Med, 79*(8), 779-783.

de Oliveira, C. G., Simpson, D. M., Nadal, J. (2001). Lumbar back muscle activity of helicopter pilots and whole-body vibration. *Journal of Biomechanics, 34*(10), 1309-1315.

Denys, E. H. (1991). AAEM minimonograph #14: The influence of temperature in clinical neurophysiology. *Muscle Nerve, 14*(9), 795-811.

Drebs, A., Norlund, A., Karlsson, P. (2002). *Tilastoja Suomen Ilmastosta 1971 - 2000 - Climatological Statistics of Finland.* Helsinki: Finnish Meteorological Institute.

Dvorak, J., Froehlich, D., Penning, L., Baumgartner, H., Panjabi, M. M. (1988). Functional radiographic diagnosis of the cervical spine: flexion/extension. *Spine, 13*(7), 748-755.

Elfering, A., Semmer, N., Birkhofer, D., Zanetti, M., Hodler, J., Boos, N. (2002). Risk factors for lumbar disc degeneration: a 5-year prospective MRI study in asymptomatic individuals. *Spine, 27*(2), 125-134.

Epperson, W. L., Burton, R. R., Bernauer, E. M. (1982). The influence of differential physical conditioning regimens on simulated aerial combat maneuvering tolerance. *Aviat Space Environ Med, 53*(11), 1091-1097.

Epperson, W. L., Burton, R. R., Bernauer, E. M. (1985). The effectiveness of specific weight training regimens on simulated aerial combat maneuvering G tolerance. *Aviat Space Environ Med, 56*(6), 534-539.

Erkintalo, M. O., Salminen, J. J., Alanen, A. M., Paajanen, H. E., Kormano, M. J. (1995). Development of degenerative changes in the lumbar intervertebral disk: results of a prospective MR imaging study in adolescents with and without low-back pain. *Radiology, 196*(2), 529-533.

Fardon, D. F., Milette, P. C., Combined Task Forces of the North American Spine Society, A. S. o. S. R., American Society of, N. (2001). Nomenclature and classification of lumbar disc pathology. Recommendations of the Combined task Forces of the North American Spine Society, American Society of Spine Radiology, and American Society of Neuroradiology. *Spine, 26*(5), E93-E113.

Finsterer, J., Mamoli, B. (1996). Temperature dependency of turn/amplitude parameters. *Pflugers Arch, 431*(6), 950-953.

Gallucci, M., Limbucci, N., Paonessa, A., Splendiani, A. (2007). Degenerative disease of the spine. *Neuroimaging Clin N Am, 17*(1), 87-103.

Garces, G. L., Medina, D., Milutinovic, L., Garavote, P., Guerado, E. (2002). Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc, 34*(3), 464-470.

Green, N. D. (2003). Acute soft tissue neck injury from unexpected acceleration. *Aviat Space Environ Med, 74*(10), 1085-1090.

Green, N. D., Brown, L. (2004). Head positioning and neck muscle activation during air combat. *Aviat Space Environ Med, 75*(8), 676-680.

Hald, H. J., Danz, B., Schwab, R., Burmeister, K., Bahren, W. (1995a). Rontgenologisch nachweisbare Wirbelsaulenveranderungen asymptomatischer junger Manner. *Rofo: Fortschritte auf dem Gebiete der Rontgenstrahlen und der Nuklearmedizin, 163*(1), 4-8.

Hald, H. J., Danz, B., Schwab, R., Burmeister, K., Bahren, W. (1995b). Rontgenologisch nachweisbare Wirbelsaulenveranderungen asymptomatischer junger Manner [Radiographically demonstrable spinal changes in asymptomatic young men]. *Rofo: Fortschritte auf dem Gebiete der Rontgenstrahlen und der Nuklearmedizin, 163*(1), 4-8.

Harms-Ringdahl, K., Ekholm, J., Schuldt, K., Nemeth, G., Arborelius, U. P. (1986). Load moments and myoelectric activity when the cervical spine is held in full flexion and extension. *Ergonomics, 29*(12), 1539-1552.

Harrison, D. D., Harrison, S. O., Croft, A. C., Harrison, D. E., Troyanovich, S. J. (1999). Sitting biomechanics part I: review of the literature. *Journal of Manipulative & Physiological Therapeutics, 22*(9), 594-609.

Helleur, C., Gracovetsky, S., Farfan, H. (1984). Tolerance of the human cervical spine to high acceleration: a modelling approach. *Aviat Space Environ Med, 55*(10), 903-909.

Hendriksen, I. J., Holewijn, M. (1999). Degenerative changes of the spine of fighter pilots of the Royal Netherlands Air Force (RNLAF). *Aviat Space Environ Med, 70*(11), 1057-1063.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D. F., Blok, J., Rau, G. et al. (1999). *European recommendations for surface electromyography*. Enschede, the Netherlands: Roessingh Research and Development.

Hoek van Dijke, G. A., Snijders, C. J., Roosch, E. R., Burgers, P. I. (1993). Analysis of biomechanical and ergonomic aspects of the cervical spine in F-16 flight situations. *J Biomech, 26*(9), 1017-1025.

Holewijn, M., Heus, R. (1992). Effects of temperature on electromyogram and muscle function. *Eur J Appl Physiol Occup Physiol, 65*(6), 541-545.

Hämäläinen, O. (1993a). *Fighter pilots' neck pain.* Academic Dissertation, University of Oulu, Oulu.

Hämäläinen, O. (1993b). Flight helmet weight, +Gz forces, and neck muscle strain. *Aviat Space Environ Med, 64*(1), 55-57.

Hämäläinen, O., Heinijoki, H., Vanharanta, H. (1998). Neck training and +Gz-related neck pain: a preliminary study. *Mil Med, 163*(10), 707-708.

Hämäläinen, O., Toivakka-Hämäläinen, S. K., Kuronen, P. (1999). +Gz associated stenosis of the cervical spinal canal in fighter pilots. *Aviat Space Environ Med, 70*(4), 330-334.

Hämäläinen, O., Vanharanta, H. (1992). Effect of Gz forces and head movements on cervical erector spinae muscle strain. *Aviation Space & Environmental Medicine, 63*(8), 709-716.

Hämäläinen, O., Vanharanta, H., Bloigu, R. (1993a). Determinants of +Gz-related neck pain: a preliminary survey. *Aviat Space Environ Med, 64*(7), 651-652.

Hämäläinen, O., Vanharanta, H., Bloigu, R. (1994a). +Gz-related neck pain: a follow-up study. *Aviat Space Environ Med, 65*(1), 16-18.

Hämäläinen, O., Vanharanta, H., Hupli, M., Karhu, M., Kuronen, P., Kinnunen, H. (1996). Spinal shrinkage due to +Gz forces. *Aviat Space Environ Med, 67*(7), 659-661.

Hämäläinen, O., Vanharanta, H., Kuusela, T. (1993b). Degeneration of cervical intervertebral disks in fighter pilots frequently exposed to high +Gz forces. *Aviat Space Environ Med, 64*(8), 692-696.

Hämäläinen, O., Visuri, T., Kuronen, P., Vanharanta, H. (1994b). Cervical disk bulges in fighter pilots. *Aviat Space Environ Med, 65*(2), 144-146.

Ineson, J., Durnell, L., Ebbage, J. L., Jarrett, D. N., Neary, C., Reed, M. A. (2004). Speed and accuracy of head- and eye-based aiming systems at high vertical acceleration. *Aviat Space Environ Med, 75*(5), 420-428.

Izquierdo, M., Hakkinen, K., Ibanez, J., Anton, A., Garrues, M., Ruesta, M. et al. (2003). Effects of strength training on submaximal and maximal endurance performance capacity in middle-aged and older men. *J Strength Cond Res, 17*(1), 129-139.

Jarvik, J. G., Hollingworth, W., Heagerty, P. J., Haynor, D. R., Boyko, E. J., Deyo, R. A. (2005). Three-year incidence of low back pain in an initially asymptomatic cohort: clinical and imaging risk factors.[see comment]. *Spine, 30*(13), 1541-1548; discussion 1549.

Jin, K., Sorock, G. S., Courtney, T., Liang, Y., Yao, Z., Matz, S. et al. (2000). Risk factors for work-related low back pain in the People's Republic of China. *Int J Occup Environ Health, 6*(1), 26-33.

Jones, J. A., Hart, S. F., Baskin, D. S., Effenhauser, R., Johnson, S. L., Novas, M. A. et al. (2000). Human and behavioral factors contributing to spine-based neurological cockpit injuries in pilots of high-performance aircraft: recommendations for management and prevention. *Mil Med, 165*(1), 6-12.

Kikukawa, A., Tachibana, S., Yagura, S. (1995). G-related musculoskeletal spine symptoms in Japan Air Self Defense Force F-15 pilots. *Aviat Space Environ Med, 66*(3), 269-272.

Kjaer, P., Leboeuf-Yde, C., Korsholm, L., Sorensen, J. S., Bendix, T. (2005). Magnetic resonance imaging and low back pain in adults: a diagnostic imaging study of 40-year-old men and women. *Spine, 30*(10), 1173-1180.

Knight, J. F., Baber, C. (2004). Neck muscle activity and perceived pain and discomfort due to variations of head load and posture. *Aviat Space Environ Med, 75*(2), 123-131.

Knudson, R., McMillan, D., Doucette, D., Seidel, M. (1988). A comparative study of G-induced neck injury in pilots of the F/A-18, A-7, and A-4. *Aviat Space Environ Med, 59*(8), 758-760.

Kokkonen, S. M., Kurunlahti, M., Tervonen, O., Ilkko, E., Vanharanta, H. (2002). Endplate degeneration observed on magnetic resonance imaging of the lumbar spine: correlation with pain provocation and disc changes observed on computed tomography diskography. *Spine, 27*(20), 2274-2278.

Kolstad, F., Myhr, G., Kvistad, K. A., Nygaard, O. P., Leivseth, G. (2005). Degeneration and height of cervical discs classified from MRI compared with precise height measurements from radiographs. *Eur J Radiol, 55*(3), 415-420.

Kramer, M., Hohl, K., Bockholt, U., Schneider, F., Dehner, C. (2013). Training effects of combined resistance and proprioceptive neck muscle exercising. *J Back Musculoskelet Rehabil, 26*(2), 189-197.

Krause, K. H., Magyarosy, I., Gall, H., Ernst, E., Pongratz, D., Schoeps, P. (2001). Effects of heat and cold application on turns and amplitude in surface EMG. *Electromyogr Clin Neurophysiol, 41*(2), 67-70.

Kuisma, M., Karppinen, J., Niinimaki, J., Ojala, R., Haapea, M., Heliovaara, M. et al. (2007). Modic changes in endplates of lumbar vertebral bodies: prevalence and association with low back and sciatic pain among middle-aged male workers. *Spine, 32*(10), 1116-1122.

Kumar, S., Narayan, Y., Amell, T. (2001). Spectral profile of superficial cervical muscles. *J Electromyogr Kinesiol, 11*(4), 269-280.

Kumar, S., Narayan, Y., Amell, T. (2003). EMG power spectra of cervical muscles in lateral flexion and comparison with sagittal and oblique plane activities. *Eur J Appl Physiol, 89*(3-4), 367-376.

Kumar, S., Narayan, Y., Amell, T., Ferrari, R. (2002). Electromyography of superficial cervical muscles with exertion in the sagittal, coronal and oblique planes. *Eur Spine J, 11*(1), 27-37.

Landau, D. A., Chapnick, L., Yoffe, N., Azaria, B., Goldstein, L., Atar, E. (2006). Cervical and lumbar MRI findings in aviators as a function of aircraft type. *Aviat Space Environ Med, 77*(11), 1158-1161.

Lange, B., Toft, P., Myburgh, C., Sjogaard, G. (2013). Effect of targeted strength, endurance, and coordination exercise on neck and shoulder pain among fighter pilots: a randomized-controlled trial. *Clin J Pain, 29*(1), 50-59.

Lantz, C. A., Klein, G., Chen, J., Mannion, A., Solinger, A. B., Dvorak, J. (2003). A reassessment of normal cervical range of motion. *Spine, 28*(12), 1249-1257.

Le Menn, M., Bigard, X., Bouron, F., Serra, A. (1995). A system for recording electrophysiological signals in flight. *Aviat Space Environ Med, 66*(5), 443-448.

Lee, C. M., Freivalds, A., Lee, S. Y. (1991). Biodynamic simulations of the effect of a neck-mounted air bag on the head/neck response during high G acceleration. *Aviat Space Environ Med, 62*(8), 747-753.

Linton, S. J., van Tulder, M. W. (2001). Preventive interventions for back and neck pain problems: what is the evidence? *Spine, 26*(7), 778-787.

Lopez-Lopez, J. A., Vallejo, P., Rios-Tejada, F., Jimenez, R., Sierra, I., Garcia-Mora, L. (2001). Determination of lumbar muscular activity in helicopter pilots: a new approach. *Aviation Space & Environmental Medicine, 72*(1), 38-43.

Lu, W. W., Bishop, P. J. (1996). Electromyographic activity of the cervical musculature during dynamic lateral bending. *Spine, 21*(21), 2443-2449.

Luoma, K., Vehmas, T., Riihimaki, H., Raininko, R. (2001). Disc height and signal intensity of the nucleus pulposus on magnetic resonance imaging as indicators of lumbar disc degeneration. *Spine, 26*(6), 680-686.

Madigan, M. L., Pidcoe, P. E. (2002). A muscle temperature compensation technique for EMG fatigue measures. *Med Sci Sports Exerc, 34*(5), 780-784.

Maiman, D. J., Sances, A., Jr., Myklebust, J. B., Larson, S. J., Houterman, C., Chilbert, M. et al. (1983). Compression injuries of the cervical spine: a biomechanical analysis. *Neurosurgery, 13*(3), 254-260.

Malfair, D., Beall, D. P. (2007). Imaging the degenerative diseases of the lumbar spine. *Magn Reson Imaging Clin N Am, 15*(2), 221-238, vi.

Mathys, R., Ferguson, S. J. (2012). Simulation of the effects of different pilot helmets on neck loading during air combat. *J Biomech, 45*(14), 2362-2367.

Mayoux-Benhamou, M. A., Barbet, J. P., Bargy, F., Vallee, C., Revel, M. (1990). Method of quantitative anatomical study of the dorsal neck muscles. Preliminary study. *Surg Radiol Anat, 12*(3), 181-185.

Mayoux-Benhamou, M. A., Revel, M. (1993). Influence of head position on dorsal neck muscle efficiency. *Electromyogr Clin Neurophysiol, 33*(3), 161-166.

Mucke, R., Heuer, D. (1989). Behaviour of EMG-parameters and conduction velocity in contractions with different muscle temperatures. *Biomed Biochim Acta, 48*(5-6), S459-464.

Naumann, F. L., Bennell, K. L., Wark, J. D. (2001). The effects of +Gz force on the bone mineral density of fighter pilots. *Aviation Space & Environmental Medicine, 72*(3), 177-181.

Naumann, F. L., Grant, M. C., Dhaliwal, S. S. (2004). Changes in cervical spine bone mineral density in response to flight training. *Aviat Space Environ Med, 75*(3), 255-259.

Netto, K. J., Burnett, A. F. (2006a). Neck muscle activation and head postures in common high performance aerial combat maneuvers. *Aviat Space Environ Med, 77*(10), 1049-1055.

Netto, K. J., Burnett, A. F. (2006b). Reliability of normalisation methods for EMG analysis of neck muscles. *Work, 26*(2), 123-130.

Netto, K. J., Burnett, A. F., Coleman, J. L. (2007). Neck exercises compared to muscle activation during aerial combat maneuvers. *Aviat Space Environ Med, 78*(5), 478-484.

Newman, D. G. (1996). Cervical intervertebral disc protrusion in an RAAF F-111C pilot: a case report. *Aviat Space Environ Med, 67*(4), 351-353.

Newman, D. G. (1997a). +GZ-induced neck injuries in Royal Australian Air Force fighter pilots. *Aviat Space Environ Med, 68*(6), 520-524.

Newman, D. G. (1997b). Head positioning for high +Gz loads: an analysis of the techniques used by F/A-18 pilots. *Aviat Space Environ Med, 68*(8), 732-735.

Newman, D. G. (2002). Helmet-mounted equipment in the high +Gz environment. *Aviat Space Environ Med, 73*(7), 730-731.

Newman, D. G., Callister, R. (1999). Analysis of the Gz environment during air combat maneuvering in the F/A-18 fighter aircraft. *Aviat Space Environ Med, 70*(4), 310-315.

Nightingale, R. W., Winkelstein, B. A., Knaub, K. E., Richardson, W. J., Luck, J. F., Myers, B. S. (2002). Comparative strengths and structural properties of the upper and lower cervical spine in flexion and extension. *J Biomech, 35*(6), 725-732.

Oksa, J., Ducharme, M. B., Rintamaki, H. (2002). Combined effect of repetitive work and cold on muscle function and fatigue. *J Appl Physiol, 92*(1), 354-361.

Oksa, J., Hämäläinen, O., Rissanen, S., Myllyniemi, J., Kuronen, P. (1996). Muscle strain during aerial combat maneuvering exercise. *Aviat Space Environ Med, 67*(12), 1138-1143.

Oksa, J., Hämäläinen, O., Rissanen, S., Salminen, M., Kuronen, P. (1999). Muscle fatigue caused by repeated aerial combat maneuvering exercises. *Aviat Space Environ Med, 70*(6), 556-560.

Oksa, J., Linja, T., Rintala, H. (2003). The effect of lumbar support on the effectiveness of anti-G straining manuevers. *Aviat Space Environ Med, 74*(8), 886-890.

Oksa, J., Rintamaki, H. (1995). Dynamic work in cold. *Arctic Med Res, 54 Suppl 2*, 29-31.

Oksa, J., Rintamaki, H., Makinen, T., Hassi, J., Rusko, H. (1995). Cooling-induced changes in muscular performance and EMG activity of agonist and antagonist muscles. *Aviat Space Environ Med, 66*(1), 26-31.

Oksa, J., Rintamaki, H., Rissanen, S. (1997). Muscle performance and electromyogram activity of the lower leg muscles with different levels of cold exposure. *Eur J Appl Physiol Occup Physiol, 75*(6), 484-490.

Orsello, C. A., Phillips, A. S., Rice, G. M. (2013). Height and in-flight low back pain association among military helicopter pilots. *Aviat Space Environ Med, 84*(1), 32-37.

Osborn, A. (1994). Normal ageing and disk degeneration. In A. Osborn (Ed.), *Diagnostic neuroradiology* (pp. 836-840). St. Louis: Mosby A.G.

Panin, N. L., Prusov, P. M. (2001). Concept of a Neck Protective Device (CNPD). *Aviat Space Environ Med, 72*(2), 155.

Panjabi, M., Cholewicki, J., Nibu, K., Grauer, J., Babat, L. B., Dvorak, J. (1998). Critical load of the human cervical spine: an in vitro experimental study. *Clin Biomech (Bristol, Avon), 13*(1), 11-17.

Panjabi, M., Crisco, J. J., Vasavada, A., Oda, T., Cholewicki, J., Nibu, K. et al. (2001). Mechanical properties of the human cervical spine as shown by three-dimensional load-displacement curves. *Spine, 26*(24), 2692-2700.

Panjabi, M., White, A. (1990). Physical properties and functional biomechanics of the spine. In A. White & M. Panjabi (Eds.), *Clinical biomechanics of the spine* (2nd ed., pp. 3-76). Philadelphia: J.B. Lippincott Co.

Petren-Mallmin, M., Linder, J. (1999). MRI cervical spine findings in asymptomatic fighter pilots. *Aviat Space Environ Med, 70*(12), 1183-1188.

Petren-Mallmin, M., Linder, J. (2001). Cervical spine degeneration in fighter pilots and controls: a 5-yr follow-up study. *Aviat Space Environ Med, 72*(5), 443-446.

Petrofsky, J., Laymon, M. (2005). Muscle temperature and EMG amplitude and frequency during isometric exercise. *Aviat Space Environ Med, 76*(11), 1024-1030.

Pfirrmann, C. W., Metzdorf, A., Zanetti, M., Hodler, J., Boos, N. (2001). Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine, 26*(17), 1873-1878.

Phillips, C. A., Petrofsky, J. S. (1983a). Neck muscle loading and fatigue: systematic variation of headgear weight and center-of-gravity. *Aviat Space Environ Med, 54*(10), 901-905.

Phillips, C. A., Petrofsky, J. S. (1983b). Quantitative electromyography: response of the neck muscles to conventional helmet loading. *Aviat Space Environ Med, 54*(5), 452-457.

Pienimäki, T. (2002). Cold exposure and musculoskeletal disorders and diseases. A review. *Int J Circumpolar Health, 61*(2), 173-182.

Pippig, T., Kriebel, J. (2000). Prevalence of cervical and lumbar disc disorders in pilots of the German armed forces. *Eur J Med Res, 5*(1), 5-8.

Rintala, H. (2012). *Military pilots' physical performance and occupational musculoskeletal disorders.* National Defence University, Helsinki.

Schall, D. G. (1989). Non-ejection cervical spine injuries due to +Gz in high performance aircraft. *Aviat Space Environ Med, 60*(5), 445-456.

Schonstein, E., Kenny, D., Keating, J., Koes, B., Herbert, R. D. (2003). Physical conditioning programs for workers with back and neck pain: a cochrane systematic review. *Spine, 28*(19), E391-395.

Seng, K. Y., Lam, P. M., Lee, V. S. (2003). Acceleration effects on neck muscle strength: pilots vs. non-pilots. *Aviat Space Environ Med, 74*(2), 164-168.

Seng, K. Y., Lee Peter, V. S., Lam, P. M. (2002). Neck muscle strength across the sagittal and coronal planes: an isometric study. *Clin Biomech (Bristol, Avon), 17*(7), 545-547.

Siitonen, S. (2000). *Effects of in-flight Gz acceleration on military aviators using modern anti-G garmets.* University of Kuopio, Kuopio.

Sjogaard, G., Sogaard, K. (1998). Muscle injury in repetitive motion disorders. *Clinical Orthopaedics & Related Research*(351), 21-31.

Snijders, C. J., Hoek van Dijke, G. A., Roosch, E. R. (1991). A biomechanical model for the analysis of the cervical spine in static postures. *J Biomech, 24*(9), 783-792.

Stewart, D., Macaluso, A., De Vito, G. (2003). The effect of an active warm-up on surface EMG and muscle performance in healthy humans. *Eur J Appl Physiol, 89*(6), 509-513.

Sward, L. (1992). The thoracolumbar spine in young elite athletes. Current concepts on the effects of physical training. *Sports Med, 13*(5), 357-364.

Thalgott, J. S., Albert, T. J., Vaccaro, A. R., Aprill, C. N., Giuffre, J. M., Drake, J. S. et al. (2004). A new classification system for degenerative disc disease of the lumbar spine based on magnetic resonance imaging, provocative discography, plain radiographs and anatomic considerations. *Spine J, 4*(6 Suppl), 167S-172S.

Thornley, L. J., Maxwell, N. S., Cheung, S. S. (2003). Local tissue temperature effects on peak torque and muscular endurance during isometric knee extension. *Eur J Appl Physiol, 90*(5-6), 588-594.

Thuresson, M., Äng, B., Linder, J., Harms-Ringdahl, K. (2003). Neck muscle activity in helicopter pilots: effect of position and helmet-mounted equipment. *Aviat Space Environ Med, 74*(5), 527-532.

van Dieen, J. H., Thissen, C. E., van de Ven, A. J., Toussaint, H. M. (1991). The electro-mechanical delay of the erector spinae muscle: influence of rate of force development, fatigue and electrode location. *Eur J Appl Physiol Occup Physiol, 63*(3-4), 216-222.

van Leusden, A. J., Prendergast, P. R., Gray, G. W. (1991). Permanent grounding and flying restrictions in Canadian Forces pilots: a 10-year review. *Aviat Space Environ Med, 62*(6), 513-516.

Vanderbeek, R. D. (1988). Period prevalence of acute neck injury in U.S. Air Force pilots exposed to high G forces. *Aviat Space Environ Med, 59*(12), 1176-1180.

Vasavada, A. N., Li, S., Delp, S. L. (2001). Three-dimensional isometric strength of neck muscles in humans. *Spine, 26*(17), 1904-1909.

Veiersted, K. B., Westgaard, R. H., Andersen, P. (1993). Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. *Scandinavian Journal of Work, Environment & Health, 19*(4), 284-290.

White, A. A., Panjabi, M. M. (1990). Kinematics of the spine. In A. A. White & M. M. Panjabi (Eds.), *Clinical biomechanics of the spine* (2nd edition ed., pp. 85-126). Philadelphia: J.B. Lippincott.

Winfield, D. A. (1999). Aircrew lumbar supports: an update. *Aviation Space & Environmental Medicine, 70*(4), 321-324.

Winkel, J., Jorgensen, K. (1991). Significance of skin temperature changes in surface electromyography. *Eur J Appl Physiol Occup Physiol, 63*(5), 345-348.

Woods, J. J., Bigland-Ritchie, B. (1983). Linear and non-linear surface EMG/force relationships in human muscles. An anatomical/functional argument for the existence of both. *Am J Phys Med, 62*(6), 287-299.

Yacavone, D. W., Bason, R. (1992). Cervical injuries during high G maneuvers: a review of Naval Safety Center data, 1980-1990. *Aviat Space Environ Med, 63*(7), 602-605.

Ylinen, J., Nuorala, S., Hakkinen, K., Kautiainen, H., Hakkinen, A. (2003). Axial neck rotation strength in neutral and prerotated postures. *Clin Biomech (Bristol, Avon), 18*(6), 467-472.

Ylinen, J., Rezasoltani, A., Julin, M. V., Virtapohja, H. A., Malkia, E. A. (1999). Reproducibility of isometric strength: measurement of neck muscles. *Clin Biomech (Bristol, Avon), 14*(3), 217-219.

Yoo, J. U., Zou, D., Edwards, W. T., Bayley, J., Yuan, H. A. (1992). Effect of cervical spine motion on the neuroforaminal dimensions of human cervical spine. *Spine, 17*(10), 1131-1136.

Äng, B. (2007). *Neck pain in air force pilots.* Karolinska Institutet, Stockholm.

Äng, B., Harms-Ringdahl, K. (2006). Neck pain and related disability in helicopter pilots: A survey of prevalence and risk factors. *Aviat Space Environ Med, 77*(7), 713-719.

Äng, B., Linder, J., Harms-Ringdahl, K. (2005). Neck strength and myoelectric fatigue in fighter and helicopter pilots with a history of neck pain. *Aviat Space Environ Med, 76*(4), 375-380.

Original publications

RESEARCH ARTICLE

Spinal MRI in Fighter Pilots and Controls: A 13-Year Longitudinal Study

Roope Sovelius, Oili Salonen, Antti Lamminen,
Heini Huhtala, and Olavi Hämäläinen

Sovelius R, Salonen O, Lamminen A, Huhtala H, Hämäläinen O. *Spinal MRI in fighter pilots and controls: a 13-year longitudinal study.* **Aviat Space Environ Med 2008; 79:685–8.**

Introduction: Although it is known that some degenerative changes occur in the spines of fighter pilots, it is not clear whether their frequent exposure to high acceleration is associated with premature development of such changes. This case-control study was designed help answer that question. ***Methods:*** There were 12 Finnish Air Force pilot cadets and their controls who were examined using cervical and lumbar magnetic resonance imaging (MRI) before the pilots started fighter training (baseline) and 13 yr later (follow-up) when the pilots had accumulated a total of 1200 ± 470 h in fighter aircraft. ***Results:*** No statistical differences were found between groups with respect to the frequency of degenerative changes in either the cervical or lumbar spine. Cervical changes in pilots were for the most part observed in the lower part of the neck, while controls showed more variability as to location. In the lumbar region, pilots showed a non-significant tendency toward more changes in disks L4-S1, including changes in signal intensity, height, protrusions, and end plates. ***Conclusion:*** Occupational exposure to acceleration in fighter aircraft did not cause significant radiological changes in the spinal column during the first 13 yr of a fighter pilot's flying career. Assessments for the need of a fighter pilot's follow-up imaging should be based on clinical outcome, not on periodic imaging.

Keywords: fighter pilot, cervical spine, lumbar spine, disk degeneration, Gz force.

PILOTS OF MODERN high-performance fighters encounter high G_z forces, and their spinal structures are consequently subjected to excessive loadings which may exceed pilots' muscular performance limits. There are reports that G_z exposure has caused acute in-flight pains and injuries (2,25).

Radiographs have shown early degenerative changes among military pilots, especially in the cervical spine. It has been discovered that pilots of high-performance fighters have an increasingly deforming arthrosis in the cervical spine compared to the controls (16). Studies using magnetic resonance imaging (MRI) have revealed a significantly larger number of cervical canal changes among experienced fighter pilots compared with their age-matched controls (13,27). A re-evaluation of their subjects by Petren-Malmen and Linder, undertaken after a follow-up period of 5 yr, indicated diminishing changes both between experienced pilots and their non-flying controls and between experienced and young pilots (28) during this period. Another study associated degenerative changes in the cervical spine with older age rather than aircraft type flown (20). Although degenerative changes of the spinal column correlate with age (1,9), regardless of symptoms (6,7), even young people often display radiological findings (11). Among a selected population of 232 Norwegian military pilot applicants, spinal radiographs of only 1/3 of them were considered normal, while 1/10 of applicants were rejected from military flight training due to radiological findings (3).

Degeneration of the spine is defined in radiological terms as loss of disk height, decreased disk and bone marrow signal intensity, and disk protrusion or herniation shown on MRI (10,18,29). Decreased signal intensity of the intervertebral disk is the most common sign of disk degeneration shown on MRI. Even though decreased signal intensity and disk height have been generally accepted as an indicator of disk degeneration (26), the signal intensity of nucleus pulposus seems to be a more feasible measure of degeneration than absolute disk height (21). In addition, the high intensity zone (HIZ) is particularly diagnostic for painful internal disk disruption (4). Vertebral endplate changes are also assumed to be associated with degenerative intervertebral disk disease (17,19). The aim of this study was to determine the possible degenerative radiological changes in the cervical and lumbar spine induced by G_z exposure in high performance military aircraft during a 13-yr follow-up period.

METHODS

Subjects

The test subjects consisted of 12 Finnish Air Force pilot cadets and their age-matched controls. The controls

---

From the Training Air Wing, Kauhava, Finland (R. Sovelius); the Department of Radiology, Helsinki University Central Hospital, Helsinki, Finland (O. Salonen, A. Lamminen); the School of Public Health, University of Tampere; Research Unit, Tampere University Hospital, Tampere, Finland (H. Huhtala); and Finnair PLC, Helsinki-Vantaa Airport, Finland (O. Hämäläinen).

This manuscript was received for review in December 2007. It was accepted for publication in April 2008.

Address reprint requests to: Roope Sovelius, Training Air Wing, P.O. Box 5, FIN-62201 Kauhava, Finland; roope.sovelius@mil.fi.

DOI: 10.3357/ASEM.2249.2008

were chosen from the same annual cohort of Army and Navy cadets. The mean age during baseline imaging was 20.9 ± 0.6 yr for the pilot group and 21.4 ± 1.0 yr for the control group, respectively. There were no exclusions in the sample size in the beginning of the study; all pilot cadets of a one course contributed to the study voluntarily. Later one control subject was excluded from the material due to the lack of follow-up MRIs. Based on general military selection criteria, the control group was similar to the pilot group with regard to contributing factors (such as social background, physical activity, smoking, suffering from no degenerative or other chronic illnesses), yet they were not exposed to the stresses of military flying later in their career.

The subjects had no history of noteworthy spinal complaints at the beginning of study, and there were no sport or motor vehicle accidents in either group during follow-up. There were no ejections from aircraft during the follow-up. One pilot had cervical disk protrusion, and another pilot a lumbar disk protrusion that were associated with high G_z flying. After the injuries both of them terminated flying high performance aircraft. Both groups met minimum military requirements in muscular strength and endurance tests during follow-up.

The subjects were informed of the details of the experimental protocol with a written informed consent, including the protective measures taken for subjects' individual privacy and filing the data. The study was approved by the Finnish Defense Forces Medical Research Register, Finnish Air Force Headquarters, which granted a Research License; and Ethical Committee of the Central Finland Hospital District.

The baseline MRIs of the cervical and lumbar spine were performed at the beginning of the subjects' military training syllabus when the pilot group had not yet been exposed to high G_z forces. Follow-up MRIs were carried out 13 ± 0.8 yr later to 12 pilots and to 11 controls. After the follow-up time, the pilot group's total mean accumulated flying time was 1500 ± 390 h, and flying time in high-performance aircraft (BAe Hawk, Saab Draken, MiG-21, F-18) capable of high-G_z maneuvering was 1200 ± 470 h.

MRI Technology

Baseline MRI was performed with a 0.1T device (Mega 4, Instrumentarium, Helsinki, Finland). Follow-up MR examinations were performed with a 1.0T device (GE Signa Horizon, UK). Both examinations included T1 and T2 weighted sagittal and axial MRI of the cervical and lumbar spine.

MRI Evaluation

The scope of the present study was more occupational than radiological, and the grading of findings was set to be simpler and more forthright than suggested in some publications (10,18,32). All symptomatic lesions have occupational significance regardless of the types of degenerative changes. On the other hand, the aim was to provide as reliable and comparable evaluations as possible between baseline and follow-up images despite the use of a different MRI technique 13 yr after baseline imaging. Two experienced neuroradiologists evaluated the images blinded to group information, and their agreement grades were used in data analysis. As the baseline images of three subjects (one pilot, two controls) were not available for this particular evaluation, the data of the respective MRI images was collected from earlier equal evaluations of these same subjects carried out by one of the grading neuroradiologists during another study.

The signal intensity of the nucleus pulposus of the intervertebral disks C2-3 – C6-7 and L2-3 – L5-S1 was visually estimated using cerebrospinal fluid at the corresponding level as an intensity reference. T2-weighted images were used, and signal intensity was graded 0-2: 0 = normal signal intensity; 1 = intermediate intensity; 2 = dark nucleus pulposus. Disk height was compared with the height of the above disk, or if this was considered abnormal, with the nearest disk regarded as "normal." Disk height was graded 0-2: 0 = no or less than 25% reduction; 1 = 25–50% reduction; and 2 = more than 50% reduction. Disk bulging was evaluated in T1 and T2 images and graded 0-2: 0 = normal; 1 = protrusion; 2 = extrusion and/or sequestration. HIZs and end plate changes were described as not present or present, graded 0 or 1, respectively. All other findings observed from images were listed separately.

Statistics

Descriptive statistics are presented as mean value with a standard deviation (± SD). Fisher's exact test was used to analyze the differences between groups. In all tests, $P = 0.05$ was considered statistically significant.

RESULTS

All evaluated changes in the cervical spine during follow-up were minor in both groups. Where grade 2 would have been applicable it was left not rated, however. Two cervical protrusions, one in the pilot group and one in the control group, were noted in baseline images, but they were not observed in follow-up images. One end plate formation was noted during follow-up in the control group; otherwise, there were no changes in protrusion, HIZ, or endplates in the subjects' cervical spines. All other changes took the form of either reduced signal intensity or reduced height of intervertebral disks. There were no significant differences between the groups, but changes in the pilot group seemed to concentrate in the lower cervical spine, i.e., C5-6 and C6-7, while degenerative changes in the control group were scattered more evenly (**Table I**).

Two spondylolisthesis in the pilot group and one spondylolysis with olisthesis in the control group were diagnosed from lumbar images. Otherwise, changes in the lumbar spine were moderate. The occurrence of changes in the pilot group was higher in the signal intensity of disks, the height of disks, protrusions, and end plates. Similarly as in the cervical spine, the changes in

TABLE I. DEGENERATIVE CHANGES IN CERVICAL DISKS.

	Pilots *N* = 12	Controls *N* = 11	*P*
Subjects with Change (n)	8	7	0.10
Affected Disks/Subject (mean)	1.25	1.71	0.14
Location of Affected Disks			
C2–3 (n)	1	2	0.37
C3–4 (n)	0	1	0.48
C4–5 (n)	1	3	0.40
C5–6 (n)	3	4	0.30
C6–7 (n)	5	2	0.18

'Affected Disks' mean was calculated from the total number of affected disks per group / number of affected subjects per group.

the pilot group were observed at a lower level: L4-5 – L5-S1. No statistically significant differences were found between the groups. (**Table II**)

DISCUSSION

A controlled 13-yr follow-up period on spinal changes with exposure to G_z forces is the longest reported among military pilot populations. Because this period encompasses a major part of most pilots' active fighter flying careers, it can be safely assumed that hypothesized early degenerative changes in the spinal column due to high G_z would become exposed during follow-up years. However, radiological changes that became evident in this study were relatively few and minor. Previous studies have indicated early degenerative changes in the cervical spine among fighter pilots (13,14,16,27), yet in this study the occurrence of the changes in MRI were similar in the two groups. However, there was a slight difference between the groups in the location of disk degeneration, which corresponds to earlier reports of injuries and degenerative changes in the lower cervical spine (8,14,16,27,28). A similar tendency was noted in the lumbar spine; especially in the L4-5 level, there was variance seen between the groups.

Technical advances were made during the follow-up period and MRI devices were developed to be more potent and accurate. Yet this has to be considered as a limitation of the study, because this makes the equal rating of different qualities of images challenging. Nevertheless, the aim was to provide reliable and comparable evaluations between baseline and follow-up images with simple grading, taking into consideration only clearly apparent and significant changes. Again, this may contain a limitation in interpreting the results and their significance. A simple grading system in MRI evaluation cuts down the documented variation; more definite grading with probable greater variation in results may more easily appear to be more statistically significant. The small study sample may also affect the statistical significance of the results.

TABLE II. DEGENERATIVE CHANGES IN LUMBAR DISKS.

	Pilots *N* = 12	Controls *N* = 11	*P*
Subjects with Change (n)	10	8	0.32
Affected Disks/Subject (mean)	1.50	1.50	0.18
Location of Affected Disks			
L1–2 (n)	0	1	0.48
L2–3 (n)	0	1	0.48
L3–4 (n)	1	0	0.52
L4–5 (n)	8	3	0.06
L5–S (n)	6	7	0.27

For explanation, see Table I.

As mentioned above, two protrusions in baseline cervical MRI were not seen in follow-up images. All other changes rated at the baseline were rerated in follow-up images, which confirmed the reliability of the image evaluation. However, changes in the images are not sufficient to detect intermittent disk protrusions that have occurred and then healed between the imaging sessions.

An awareness of pilots' spinal injuries and degenerative changes has arisen during the past decade. The baseline images were performed in 1993–1994. Since then pilots have perhaps more openly discussed their symptoms with physicians, which has resulted in earlier diagnosis and treatment. In addition, physical conditioning programs have been developed and directed to pilots, and head support strategies have been taught and implemented more than before. Also, lighter helmet weights may have a positive effect (12), even though this advantage is lost, at least partially, due to the increased mass of modern helmet-mounted devices (24,30,33). These things combined may have contributed to degenerative changes not developing as prematurely as was reported earlier.

Reports indicate that degenerative changes in the lumbar spine are common even among young populations, and these changes increase with age (6,26). On the other hand, these changes seem to have a tendency to shift from disk injuries to the narrowing of the spinal canal with aging (22,26). Studies undertaken among military pilot populations also support the theory that degenerative changes seemed to be associated more with age rather than just with G_z exposure (5,16,20,28). However, due to the cumulative higher mass of the upper torso, hypergravitational forces subject the lower lumbar spine to greater loadings than to structures above it. The effects of high G_z loadings on lower lumbar segments may also increase if the lower back is inadequately supported. In this case, the pilot may slump into his seat during G_z; this causes reduction in lumbar lordosis, which in turn potentially increases misalignment and loading moments in the disks and increases disk pressure (15).

The findings of this study suggest that pathophysiological changes in the spine as verified with MRI only partly explain the occurrence of neck and back pains suffered by fighter pilots. There seems to be a tendency toward more combined association of physical loading, perceived back pain, and MRI findings (34), but it has been reported that all stress-induced loadings do not appear in MRI (23,31). Combining radiological images with physical fitness and pain survey data could provide more evident links between fighter pilots' occupational loading and degenerative changes of the spine. Still, it is possible that some degenerative effects of G_z-loading will appear years later.

In this study, high G_z exposures encountered during over 1200 h flying time did not cause significant radiological changes on the spinal column during the subject pilots' active flying career, which is contrary to other studies (13,16). However, there was a tendency to an increased rate of changes in L4-5. In addition, not all effects of loading on the spinal column may appear in MRI. Based on this study, periodical cervical or lumbar MRI follow-ups are not recommended for fighter pilots, and it is suggested that assessing the need for imaging be based on clinical outcome.

ACKNOWLEDGMENTS

This study was supported by grants from the Work Environment Fund of the Ministry of Finance and the Finnish Air Force.

The authors wish to acknowledge the personnel of the Department of Radiology of the former Central Military Hospital, Helsinki, Finland, for their contribution to this study.

REFERENCES

1. Abdulkarim JA, Dhingsa R, Finlay DBL. Magnetic resonance imaging of the cervical spine: frequency of degenerative changes in the intervertebral disc with relation to age. Clin Radiol 2003; 58:980–4.
2. Andersen HT. Neck injury sustained during exposure to high-G forces in the F16B. Aviat Space Environ Med 1988; 59:356–8.
3. Andersen HT, Wagstaff AS, Sverdrup HU. Spinal X-ray screening of high performance fighter pilots. Aviat Space Environ Med 1991; 62:1171–3.
4. Aprill C, Bogduk N. High-intensity zone: a diagnostic sign of painful lumbar disc on magnetic resonance imaging. Br J Radiol 1992; 65:361–9.
5. Aydog ST, Turbedar E, Demirel AH, Tetik O, Akin A, Doral MN. Cervical and lumbar spinal changes diagnosed in four-view radiographs of 732 military pilots. Aviat Space Environ Med 2004; 75:154–7.
6. Boden SD, Davis DO, Dina TS, Patronas NJ, Wiesel SW. Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. J Bone Joint Surg Am 1990; 72:403–8.
7. Boden SD, McCowin PR, Davis DO, Dina TS, Mark AS, Wiesel S. Abnormal magnetic-resonance scans of the cervical spine in asymptomatic subjects. A prospective investigation. J Bone Joint Surg Am 1990; 72:1178–84.
8. Burton R. Cervical spinal injury from repeated exposures to sustained acceleration. Neuilly-sur-Seine Cedex, France: NATO RTO; 1999. NATO RTO-TR-4, AC/323(HFM)TP/9.
9. Erkintalo MO, Salminen JJ, Alanen AM, Paajanen HE, Kormano MJ. Development of degenerative changes in the lumbar intervertebral disk: results of a prospective MR imaging study in adolescents with and without low-back pain. Radiology 1995; 196:529–33.
10. Fardon DF, Milette PC; Combined Task Forces of the North American Spine Society, American Society of Spine Radiology, and American Society of Neuroradiology. Nomenclature and classification of lumbar disc pathology. Recommendations of the Combined Task Forces of the North American Spine Society, American Society of Spine Radiology, and American Society of Neuroradiology. Spine 2001; 26:E93–113.
11. Hald HJ, Danz B, Schwab R, Burmeister K, Bahren W. Rontgenologisch nachweisbare Wirbelsaulenveranderungen asymptomatischer junger Manner [Radiographically demonstrable spinal changes in asymptomatic young men]. ROFO Fortschr Geb Rontgenstr Nuklearmed 1995; 163:4–8.
12. Hamalainen O. Flight helmet weight, +Gz forces, and neck muscle strain. Aviat Space Environ Med 1993; 64:55–7.
13. Hamalainen O, Vanharanta H, Kuusela T. Degeneration of cervical intervertebral disks in fighter pilots frequently exposed to high +Gz forces. Aviat Space Environ Med 1993; 64:692–6.
14. Hamalainen O, Toivakka-Hamalainen SK, Kuronen P. +Gz associated stenosis of the cervical spinal canal in fighter pilots. Aviat Space Environ Med 1999; 70:330–4.
15. Harrison DD, Harrison SO, Croft AC, Harrison DE, Troyanovich SJ. Sitting biomechanics part I: review of the literature. J Manipulative Physiol Ther 1999; 22:594–609.
16. Hendriksen IJ, Holewijn M. Degenerative changes of the spine of fighter pilots of the Royal Netherlands Air Force (RNLAF). Aviat Space Environ Med 1999; 70:1057–63.
17. Kokkonen SM, Kurunlahti M, Tervonen O, Ilkko E, Vanharanta H. Endplate degeneration observed on magnetic resonance imaging of the lumbar spine: correlation with pain provocation and disc changes observed on computed tomography diskography. Spine 2002; 27:2274–8.
18. Kolstad F, Myhr G, Kvistad KA, Nygaard OP, Leivseth G. Degeneration and height of cervical discs classified from MRI compared with precise height measurements from radiographs. Eur J Radiol 2005; 55:415–20.
19. Kuisma M, Karppinen J, Niinimäki J, Ojala R, Haapea M, Heliövaara M, et al. Modic changes in endplates of lumbar vertebral bodies: prevalence and association with low back and sciatic pain among middle-aged male workers. Spine 2007; 32:1116–22.
20. Landau DA, Chapnick L, Yoffe N, Azaria B, Goldstein L, Atar E. Cervical and lumbar MRI findings in aviators as a function of aircraft type. Aviat Space Environ Med 2006; 77:1158–61.
21. Luoma K, Vehmas T, Riihimaki H, Raininko R. Disc height and signal intensity of the nucleus pulposus on magnetic resonance imaging as indicators of lumbar disc degeneration. Spine 2001; 26:680–6.
22. Mariconda M, Galasso O, Imbimbo L, Lotti G, Milano C. Relationship between alterations of the lumbar spine, visualized with magnetic resonance imaging, and occupational variables. Eur Spine J 2007; 16:255–66.
23. Milette PC, Fontaine S, Lepanto L, Cardinal E, Breton G. Differentiating lumbar disc protrusions, disc bulges, and discs with normal contour but abnormal signal intensity. Magnetic resonance imaging with discographic correlations. Spine 1999; 24:44–53.
24. Newman DG. Helmet-mounted equipment in the high +Gz environment. Aviat Space Environ Med 2002; 73:730–1.
25. Oksa J, Hamalainen O, Rissanen S, Myllyniemi J, Kuronen P. Muscle strain during aerial combat maneuvering exercise. Aviat Space Environ Med 1996; 67:1138–43.
26. Osborn A. Normal ageing and disk degeneration. St. Louis: Mosby A.G.; 1994:836–40.
27. Petren-Mallmin M, Linder J. MRI cervical spine findings in asymptomatic fighter pilots. Aviat Space Environ Med 1999; 70:1183–8.
28. Petren-Mallmin M, Linder J. Cervical spine degeneration in fighter pilots and controls: a 5-yr follow-up study. Aviat Space Environ Med 2001; 72:443–6.
29. Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N. Magnetic resonance classification of lumbar intervertebral disc degeneration. Spine 2001; 26:1873–8.
30. Phillips CA, Petrofsky JS. Neck muscle loading and fatigue: systematic variation of headgear weight and center-of-gravity. Aviat Space Environ Med 1983; 54:901–5.
31. Siivola SM, Levoska S, Tervonen O, Ilkko E, Vanharanta H, Keinanen-Kiukaanniemi S. MRI changes of cervical spine in asymptomatic and symptomatic young adults. Eur Spine J 2002; 11:358–63.
32. Thalgott JS, Albert TJ, Vaccaro AR, Aprill CN, Giuffre JM, Drake JS, Henke JP. A new classification system for degenerative disc disease of the lumbar spine based on magnetic resonance imaging, provocative discography, plain radiographs and anatomic considerations. Spine J 2004; 4(6, Suppl.):167S–72S.
33. Thuresson M, Ang B, Linder J, Harms-Ringdahl K. Neck muscle activity in helicopter pilots: effect of position and helmet-mounted equipment. Aviat Space Environ Med 2003; 74:527–32.
34. Videman T, Battie MC, Gibbons LE, Maravilla K, Manninen H, Kaprio J. Associations between back pain history and lumbar MRI findings. Spine 2003; 28:582–8.

Ambient Temperature and Neck EMG with $+G_z$ Loading on a Trampoline

Roope Sovelius, Juha Oksa, Harri Rintala,
Heini Huhtala, and Simo Siitonen

Sovelius R, Oksa J, Rintala H, Huhtala H, Siitonen S. *Ambient temperature and neck EMG with +Gz loading on a trampoline.* **Aviat Space Environ Med 2007; 78:574–8.**

Introduction: Fighter pilots who are frequently exposed to severe cold ambient temperatures experience neck pain disabilities and occupational disorders more often than those who are not so exposed. We hypothesized that a cold-induced increase in muscle strain might lead to in-flight neck injuries. The aims of this study were to measure the level of cooling before takeoff and to determine muscle strain under G_z loading (0 to $+4$ G_z) at different temperatures. ***Methods:*** Test subjects' ($n = 14$) skin temperature (T_{skin}) over the trapezoids was measured before the walk to the aircraft and again in the cockpit (air temperature −14°C). The subjects then performed trampoline exercises in two different ambient temperatures (−2°C and +21°C) after a 30-min period at the respective temperatures. EMG activity of the sternocleidomastoid (SCM), cervical erector spinae (CES), trapezoid (TRA), thoracic erector spinae (TES) muscles, and T_{skin} of the SCM and TRA were measured. ***Results:*** T_{skin} over the trapezoids decreased from 30.1 ± 1.7°C to 27.8 ± 2.6°C ($p < 0.001$) before takeoff. The change of muscle strain in cold was +11.0% in SCM, +14.9% in CES, +3.7% in TRA, and −1.7% in TES. Change was statistically significant in the cervical, uncovered area (SCM, CES). The linear regression model indicated a 2.6% increase in muscle strain per every decreased degree centigrade in skin temperature over the SCM. ***Conclusion:*** Superficial cooling over the neck muscles was significant prior to takeoff. Muscle loading in the cold caused higher EMG activity. A major increase in muscle strain was seen in the cervical muscles. These findings suggest a cold-induced increase in muscle strain during in-flight G_z loading.

Keywords: fighter pilot, cold, muscle loading, neck injury.

THE NECK AREA is a fully-equipped fighter pilot's most lightly clothed part of the body. When operating in cold environments, fighter pilots' neck muscle temperatures are likely to decrease prior to takeoff and before the cockpit warms up. Muscle performance is significantly less efficient with subnormal muscle as compared to normal muscle temperatures. Even very superficial cooling is sufficient to substantially decrease performance (11). The maximal force production and coordination of muscles decrease in a cold environment, especially during dynamic work (2,14). Similar changes in muscle performance can be found in static work, though the degree of performance decrement may be lower compared with dynamic work (7,9,20).

In general, an association between cold exposure during work and musculoskeletal complaints or diseases has been reported (8,18). In particular, repetitive work in cold causes higher EMG activity and fatigue than work in thermoneutral conditions, possibly creating a higher risk for overuse injuries (13). The relationship between muscle temperature and EMG activity has been reported to be linear, therefore the use of EMG as an indicator of muscle strain is warranted (10,12,17).

Fighter pilots risk cervical muscle strain during high $+G_z$ loading (5,6,15), therefore neck pain and injuries are common in the Finnish Air Force. According to a Finland Aero Medical Centre survey of all fighter pilots, as well as from follow-up of annual examinations, occupational neck disorders and high-G related neck pain disabilities are more frequent among Finnish fighter pilots in a northern squadron located in Rovaniemi (66.56°N, 25.80°E) when compared with other squadrons further south (61–64°N) (Finnish Meteorological Institute; unpublished observations, 1971–2000). In Rovaniemi, wintertime is longer and colder: thermal winter (daily averaged temperatures below 0°C) is, on average, 180 d vs. the 140–150 d where other squadrons are located. The number of cold days in Rovaniemi, e.g., when daily temperature decreases below −10°C, is annually 92 d vs. other squadrons' 49 to 65 d. These statistics are based on 30-yr follow-up (1971–2000) (3). All pilots fly the same aircraft type (F-18), and flight operations are identical in all squadrons except the training squadron, which operates with BAe Hawks and provides basic jet flight and tactical training.

It is hypothesized that pilots who are exposed more frequently to cold ambient temperatures in their duties are also at higher risk for neck injuries due to decreased muscular performance in the cervical muscles. It is not known how much cooling occurs in fighter pilots' cervical areas before takeoff when operating in cold environments, or how muscle strain under G_z loading changes due to cooling. The aims of this study were to measure the level of cooling before takeoff and to de-

---

From the Training Air Wing, Kauhava, Finland (R. Sovelius); the Finnish Institute of Occupational Health, Oulu, Finland (J. Oksa); Finnish Air Force Headquarters, Tikkakoski, Finland (H. Rintala, S. Siitonen); and the School of Public Health, University of Tampere, Finland (H. Huhtala).

This manuscript was received for review in November 2006. It was accepted for publication in February 2007.

Address reprint requests to: Roope Sovelius, Training Air Wing, P.O. Box 5, FIN-62201 Kauhava, Finland; roope.sovelius@mil.fi.

termine the effect of cold ambient temperature on muscle strain in the cervical area under G_z loading.

METHODS

The subjects were 14 Finnish Air Force volunteer pilot cadets (13 men; 1 woman). Subjects' mean age was 21.5 ± 0.9 yr; height, 178.3 ± 0.1 cm; weight, 74.0 ± 8.2 kg; and body mass index, 23.2 ± 1.9 $kg \cdot m^{-2}$. At the time of the measurements, the cadets were in the beginning of their jet training with high G_z exposures. All were fit to fly and none had a history of, or current, neck pain or other neck disorders. They did not have any supervised, specific neck training program, but they were all trained to exercise on a trampoline. The subjects were informed of the details of the experimental protocol and the study was granted approval by the Finnish Defense Force Medical Research Register, Finnish Air Force Headquarters Research License, and The Ethical Committee of Central Finland Hospital District.

Phase 1: Preflight Skin Temperatures on the Platform

The exposure time during cooling was measured. During active flying duty, the walk to the aircraft (BAe Hawk mk51), preflight checks before starting up the engine, and time to takeoff were measured. Subjects were informed regarding the purpose of the study and that the measurements would not affect the sortie the pilots were going to fly. They were asked to perform routinely and were not aware of the time measurements. Appropriate and uniform clothing was worn. The psychological effects of the measurements were considered insignificant, and thus their possible effects on the skin temperature due to blood flow changes were excluded from the analyses. Skin temperature on the trapezoid muscle was measured with a thermocouple (YSI 400 series, Yellow Springs Instruments, Dayton, OH) and a datalogger (Squirrelmeter 1200, Grant Instruments Ltd, Cambridge, UK) before the walk to the aircraft and in the cockpit just before the aircraft's engine was started and the canopy was closed. Both measurements were performed with subjects in a sitting position. Due to technical problems with measuring the skin temperature of uncovered sternocleidomastoid muscles in the ambient temperature (−14°C), these measurements were excluded from the results. The measurements were performed at Training Air Wing, Kauhava AFB, Finland (63.10°N, 23.80°E) in January. The ambient temperature was recorded at Kauhava AFB's weather station.

Phase 2: Muscle Strain at Two Different Temperatures on a Trampoline

In the second part of the study, test subjects performed trampoline exercises in two different ambient temperatures, −2°C (cold) and +21°C (thermoneutral), corresponding to mild winter and summer conditions in Finland. Despite the fact that temperatures in Finland are quite variable in different parts of country during the winter, as described earlier, the temperatures are more alike during the summer. The average high temperature of a day in July is around +21°C at all fighter squadron locations (3). A thermoneutral indoor temperature of +21°C was considered a baseline measurement. Outside temperature was averaged at −2°C during previously set measuring days.

Exercises were performed in random order. Due to the relatively mild winter conditions, subjects were cooled down 30 min at −2°C before exercising in the cold to mimic the cooling that occurred during their flying duty. The change in skin temperatures in phase 2 was considered greater than those that occurred during identical cooling times in phase 1 of the study; hence the aim was to measure the change in muscle strain due to different skin temperatures. Skin temperature over the sternocleidomastoides (uncovered area) and trapezoids (underneath the clothed area) was measured bilaterally (with the same thermometer as described above) in both conditions. Subjects wore the appropriate winter or summer flight suit, depending on the ambient temperature, for a more realistic occupational setting. The goal was to determine the effect of cold ambient temperature on muscle strain, so flight helmets were not used in order to avoid extra weight-induced loading on the muscles. During the cooling time and while on the trampoline, subjects wore wool hats to avoid head cooling and excess heat loss.

A round trampoline with a diameter of 4.3 m (Jump-King, Inc., Portland, OR) was used. Ambient temperature did not change the characteristics of the trampoline. This was determined by dropping a 5-kg gym ball from a constant height with a MoTec ADL Datalogger and triple axis G-sensor (Printsport Oy, Lievestuore, Finland) attached. The bounce height and vertical acceleration were identical in both temperatures. Consequently, the accelerations the test subjects experienced were similar in both temperatures.

Subjects performed basic trampoline bouncing and hand and knee bouncing for 30 s each, with no recovery time between sets. Basic bouncing with the head kept in a neutral position simulates low G_z loading. This generally loads muscles in the neck region. During hand and knee bouncing, only the hands and knees touch the trampoline during the contact phase. This exercise especially loads the cervical muscles because during bouncing the test subject needs to stabilize his/her head and avoid whiplash movement.

On a separate occasion, vertical acceleration measurements ($n = 4$) during bouncing were performed with a G-sensor that was fixed to the helmet. Vertical acceleration during basic trampoline bouncing varied between 0 and +4 G_z. A sample of the acceleration curve as a function of time is shown in **Fig. 1**.

During the exercises, EMG activity of the right and left sternocleidomastoid (SCM), cervical erector spinae (CES), thoracic erector spinae (TES), and trapezoid (TRA) muscles were measured using bipolar surface electrodes. Measured EMG was compared with the EMG during maximal voluntary contraction (MVC), and EMG level as well as muscle strain were determined as a percent of MVC (%MVC). Muscle strain was determined using a portable eight-channel EMG device (ME3000P, Mega Electronics Ltd., Kuopio, Finland). The bipolar EMG recordings were made using pre-gelled

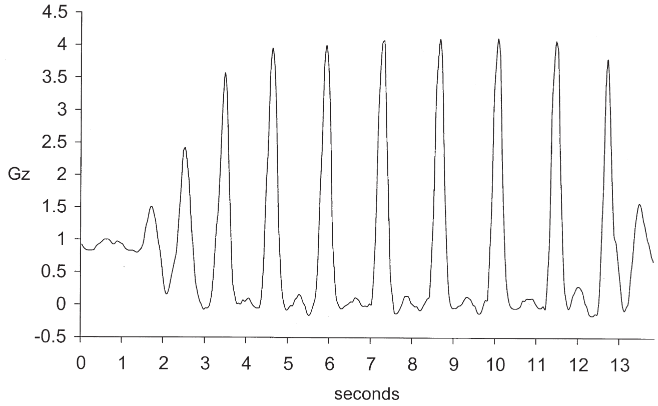


Fig. 1. Vertical acceleration during basic trampoline bouncing.

surface electrodes (Medicotest M-OO-S, Olstykke, Denmark). The electrodes were placed longitudinally on the muscles; the distance between the measurement surfaces of the electrodes was 2 cm. The ground electrodes were placed on inactive tissue. The measured signal was preamplified 1000 times. The signal-band between 20 and 500 Hz was full-wave rectified and averaged with a 100-ms time constant.

Statistics

Means with SD for measured time or temperatures and otherwise mean differences with 95% confidence intervals are given as descriptive statistics. A paired *t*-test was used to compare changes in temperatures as well as loading in different temperatures. A linear regression model was used to analyze the correlation of skin temperature change and change in muscle strain under Gz. Paired changes of skin temperatures of the SCM and TRA (independent variable) and %MVC (dependent variable) were included in the linear regression analysis. Pearson's correlation coefficient and R^2 as a coefficient of determination were used to explain the regression model. Test subjects acted as their own controls. In all tests, a p-value less than 5% (< 0.05) was considered statistically significant.

RESULTS

The walk to the aircraft and preflight checks before closing the canopy and starting the engine took on average 6 ± 1 min. The time between the walk and the takeoff was 16 ± 3 min. Ambient temperature during measurements was −14.2 ± 2.2°C. Skin temperature over the TRA decreased from 30.1 ± 1.7°C to 27.8 ± 2.6°C ($p < 0.001$) during the time between the walk and the closing of the canopy.

When the subjects were cooled down in −1.5 ± 3.6°C conditions before trampoline exercise in the cold, skin temperature over the SCM decreased from 34.5 ± 0.6°C to 31.1 ± 2.1°C ($p < 0.001$) and over the TRA from 34.4 ± 0.7°C to 33.5 ± 1.1°C ($p < 0.001$). Skin temperature did not change during the exercises. The increase of muscle strain was statistically significant in the SCM and CES in the uncovered area. In the lower muscles, no significant differences were seen. The deviation was greatest in the TES muscles (**Table I**).

A regression model indicates a 2.6% unit increase in %MVC per every centigrade of skin temperature decrease over the SCM. Measurements over the TRA presented a greater deviation in %MVC within the tight slope of the temperature changes without any correlation between variables. Pearson's correlation coefficients were 0.27 and 0.18, respectively (**Fig. 2**).

DISCUSSION

The degree of cooling of the neck area in cold conditions has not been documented previously. Pilots operating in high latitudes must often work in ambient temperatures of less than −25°C. The results of this study show that skin temperature decreases significantly during the walk to the aircraft and during preflight checks, even in a more moderate environment (−14°C). This cooling continues for 10 min more during taxiing. The cooling ends and the cockpit starts to warm up once the plane is airborne. The longer the transit flight, the longer the time for a pilot's muscles to warm up again before high-Gz maneuvering begins, and vice versa. The magnitude and significance of this phenomenon still need to be elucidated, but the preflight cooling effect may have significance in terms of more frequent cervical disorders among fighter pilots in northern squadrons (more extreme cold conditions) vs. southern ones.

Freezing conditions on the platform rendered measurements of skin temperature over the SCM unreliable. Ambient environment may also have affected the measured values of skin temperature over the TRA underneath the clothes. However, descriptive figures of mean temperatures of 27.8°C with a relatively small deviation (SD ± 2.6) supports satisfactory accuracy for the measurements performed.

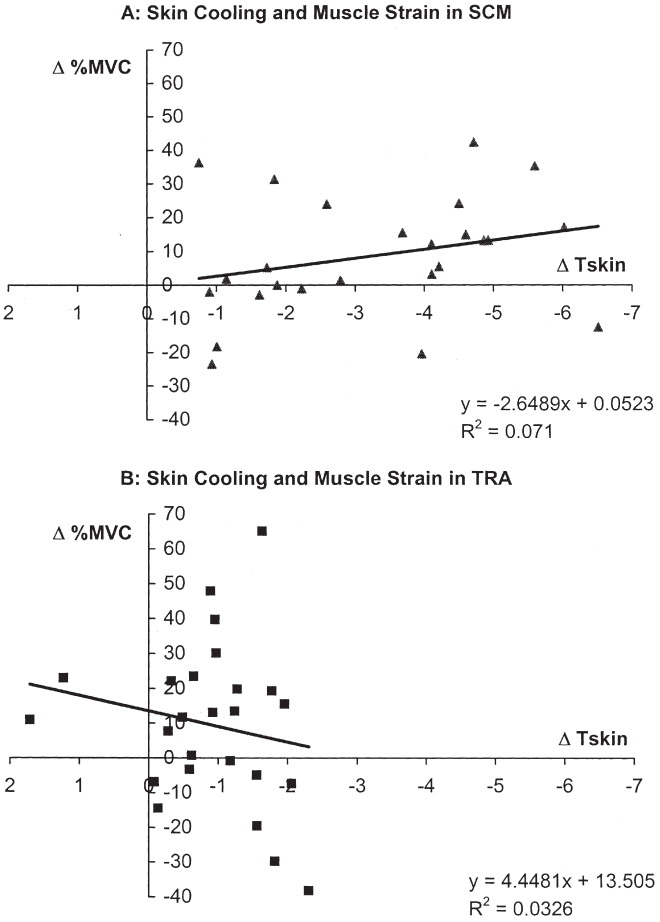
Trampoline simulated Gz loading in a cold environment was performed in a higher temperature (−2°C) compared with measured temperatures at the platform;

TABLE I. THE EFFECT OF AMBIENT TEMPERATURE ON MUSCLE STRAIN (EMG) DURING G-LOADING ON A TRAMPOLINE.

Muscle	%MVC (+21°C)	CI95%	%MVC (−2°C)	CI95%	Δ MVC (%)*	p
SCM	45.5	40.1 to 50.9	50.5	44.3 to 57.3	11.0	<0.001
CES	53.4	43.5 to 63.3	61.3	46.6 to 76.0	14.9	<0.001
TRA	45.5	30.5 to 60.5	47.2	33.4 to 61.0	3.7	0.443
TES	49.3	38.9 to 60.3	48.2	39.4 to 57.0	−2.1	0.452

SCM = sternocleidomastoides, CES = cervical erector spinae; TRA = trapezoids; TES = thoracal erector spinae; %MVC = muscle strain as a percent of maximal voluntary contraction in a given ambient temperature.

*Δ MVC (%) is percentile change of individual changes, thus it is not equal to the difference between averaged %MVC (+21°C) and %MVC (−2°C).


A: Skin Cooling and Muscle Strain in SCM

B: Skin Cooling and Muscle Strain in TRA

Fig. 2. Linear regression analysis: the change in muscle strain (Δ%MVC) under Gz as a function of muscle cooling (change in skin temperature: ΔT_{skin}): A) sternocleidomastoides (SCM); and B) trapezoids (TRA). R^2 = coefficient of determination.

however, a significant decrease in skin temperature was still found. This most likely indicates muscle cooling and, consequently, the greater muscle strain observed, especially in the lightly clothed cervical area (SCM and CES). In the better-covered lower muscles (TES and TRA muscles), the effect was not as clear, even though the smaller temperature drop there was significant, too.

The authors were not able to conduct both phases of this study in identical ambient temperatures. The air temperature observed on the platform prior to the flight in phase 1 of the study was −14°C, but prior to the trampoline exercises in phase 2 was −2°C. Cooling of the neck muscles was considered more important than ensuring an equal cooling time between the two phases; thus the cooling time was prolonged by up to 30 min. However, the lack of equivalence, both in ambient temperatures and time for cold exposure, limits the application of our results.

Gz loading on a trampoline causes an intensive impact on muscles. Thus, EMG activity was analyzed only during the contact phase (around +4 Gz), excluding the flight phase, during which muscle strain is less. These factors may explain the higher %MVC levels in this study compared with the in-flight measurements reported in the literature (5,6,16).

Cooling could affect the amplitude of the EMG by decreasing conduction velocity, modifying the shape of the action potential, or changing the impedance of the skin. However, in this context, the literature reports somewhat contradictory effects of cooling on EMG activity (4,9,17,21). It may be argued that the observed %MVC changes in this study reflect physiological changes in muscle function rather than methodological alteration, since some individual decreases in myoelectrical activity were observed in the cold. In this study EMG analyses were performed without specific temperature monitoring and adjustment.

There are some studies where a similar phenomenon is presented and correlation between muscular temperature and activity in the EMG is described as linear, yet the individual deviation seems to differ greatly (1,10,12,17). As seen in Fig. 2, the deviation of changes was great. In the TRA muscles, the change in %MVC was broad in a tight envelope of temperature change. In addition, equal EMG measurements are most difficult over the TRA muscles of different individuals. Thus, any meaningful tendency cannot be observed in the results. The linear model is more useful with measurements over the SCM muscles because individual changes and the three-fold temperature change factor deviate less compared with those over the TRA. Nevertheless, the regression equation for the SCM is not statistically significant and its degree of explanation is only 7%. Even though not statistically significant, there may have been some considerable effects in physiological level. Cooling in the colder environment produced increased muscle strain under Gz loading in the neck area. However, changes in muscle strain due to cooling were variable, and the numbers presented above should be considered to indicate the magnitude of the phenomenon rather than constant values. The phenomenon presented here may lead to a smaller difference between maximal muscle capacity and muscle capacity needed under high Gz. The smaller the gap, the greater the risk for injuries. It is suggested that this may be partly related to the higher incidence of neck disorders among fighter pilots who are exposed more frequently to cold ambient temperatures. However, in the present study we were not able to definitely support this hypothesis.

In conclusion, it is suggested that when operating in winter conditions, special attention needs to be paid to the basics. Preventing the cooling of muscles may be beneficial in reducing pilots' muscle strain as seen from the trampoline experiment presented here. Preflight warm-up also enhances muscle activation and increases power output (19), as well as increasing muscle temperature. These countermeasures buffer the cooling effect before takeoff and help to maintain pilot performance and protect physical health.

ACKNOWLEDGMENTS

This study was supported by a grant from the Work Environment Fund of the Ministry of Finance.

REFERENCES

1. Davies CT, Young K. Effect of temperature on the contractile properties and muscle power of triceps surae in humans. J Appl Physiol 1983; 55:191–5.

2. Denys EH. AAEM minimonograph #14: the influence of temperature in clinical neurophysiology. Muscle Nerve 1991; 14:795–811.
3. Drebs A, Norlund A, Karlsson P. Tilastoja Suomen Ilmastosta 1971–2000 — climatological statistics of Finland. Helsinki: Finnish Meteorological Institute; 2002.
4. Finsterer J, Mamoli B. Temperature dependency of turn/amplitude parameters. Pflugers Arch 1996; 431:950–3.
5. Green ND, Brown L. Head positioning and neck muscle activation during air combat. Aviat Space Environ Med 2004; 75: 676–80.
6. Hamalainen O. Flight helmet weight, +Gz forces, and neck muscle strain. Aviat Space Environ Med 1993; 64:55–7.
7. Holewijn M, Heus R. Effects of temperature on electromyogram and muscle function. Eur J Appl Physiol Occup Physiol 1992; 65:541–5.
8. Jin K, Sorock GS, Courtney T, et al. Risk factors for work-related low back pain in the People's Republic of China. Int J Occup Environ Health 2000; 6:26–33.
9. Krause KH, Magyarosy I, Gall H, et al. Effects of heat and cold application on turns and amplitude in surface EMG. Electromyogr Clin Neurophysiol 2001; 41:67–70.
10. Madigan ML, Pidcoe PE. A muscle temperature compensation technique for EMG fatigue measures. Med Sci Sports Exerc 2002; 34:780–4.
11. Oksa J, Rintamaki H. Dynamic work in cold. Arctic Med Res 1995; 54 (Suppl. 2):29–31.
12. Oksa J, Rintamaki H, Rissanen S. Muscle performance and electromyogram activity of the lower leg muscles with different levels of cold exposure. Eur J Appl Physiol Occup Physiol 1997; 75:484–90.
13. Oksa J, Ducharme MB, Rintamaki H. Combined effect of repetitive work and cold on muscle function and fatigue. J Appl Physiol 2002; 92:354–61.
14. Oksa J, Rintamaki H, Makinen T, et al. Cooling-induced changes in muscular performance and EMG activity of agonist and antagonist muscles. Aviat Space Environ Med 1995; 66:26–31.
15. Oksa J, Hamalainen O, Rissanen S, et al. Muscle strain during aerial combat maneuvering exercise. Aviat Space Environ Med 1996; 67:1138–43.
16. Oksa J, Hamalainen O, Rissanen S, et al. Muscle fatigue caused by repeated aerial combat maneuvering exercises. Aviat Space Environ Med 1999; 70:556–60.
17. Petrofsky J, Laymon M. Muscle temperature and EMG amplitude and frequency during isometric exercise. Aviat Space Environ Med 2005; 76:1024–30.
18. Pienimaki T. Cold exposure and musculoskeletal disorders and diseases. A review. Int J Circumpolar Health 2002; 61:173–82.
19. Stewart D, Macaluso A, De Vito G. The effect of an active warm-up on surface EMG and muscle performance in healthy humans. Eur J Appl Physiol 2003; 89:509–13.
20. Thornley LJ, Maxwell NS, Cheung SS. Local tissue temperature effects on peak torque and muscular endurance during isometric knee extension. Eur J Appl Physiol 2003; 90:588–94.
21. Winkel J, Jorgensen K. Significance of skin temperature changes in surface electromyography. Eur J Appl Physiol Occup Physiol 1991; 63:345–8.

RESEARCH ARTICLE

Neck Muscle Strain When Wearing Helmet and NVG During Acceleration on a Trampoline

ROOPE SOVELIUS, JUHA OKSA, HARRI RINTALA,
HEINI HUHTALA, AND SIMO SIITONEN

SOVELIUS R, OKSA J, RINTALA H, HUHTALA H, SIITONEN S. *Neck muscle strain when wearing helmet and NVG during acceleration on a trampoline.* **Aviat Space Environ Med 2008; 79:112–6.**

Introduction: The helmet-mounted equipment worn by military pilots increases the weight of the helmet system and shifts its center of gravity, increasing the loads on neck structures, especially during acceleration. The aim of this study was to determine neck muscle strain with different head-loads during trampoline-induced G loads (0 to +4 G). ***Methods:*** Under three conditions [no helmet, helmet, helmet with night vision goggles (NVG)], 14 subjects performed trampoline exercises including basic, hand-and-knee, and back bouncing. EMG activity was measured for the sternocleidomastoid (SCM), cervical erector spinae (CES), trapezoid (TRA), and thoracic erector spinae (TES) muscles. Muscle strain was determined as a percentage of maximal voluntary contraction (%MVC). ***Results:*** For the three exercises combined, the following significant changes were found: compared to control, the helmet increased muscle strain by 18%, 28%, and 18% in the SCM, CES, and TRA, respectively; NVG produced a further increase of 11% in the SCM and 6% in the CES. During back bouncing, the helmet increased muscle strain by 14% in the SCM and 19% in the CES, and NVG further increased this strain by 14% in the SCM. Hand-and-knee bouncing loaded extensors: the helmet caused increases of 46% in the CES and 29% in the TES, while NVG produced a further 13% increase in CES activation. ***Conclusion:*** Helmet weight alone had a large effect on muscular workload. The additional frontal weight of the NVG caused a further increase in the activity of cervical muscles that were already subjected to high strain.

Keywords: helmet-mounted systems, cervical, training, injury prevention, EMG.

THE MODERN MILITARY pilot's helmet is not just a piece of protective equipment but also a mounting platform for devices that enhance the pilot's performance. These devices include night vision goggles (NVG), head-up displays, and sighting systems, as well as multiple visors and chemical protective masks. These additional items increase the load on the cervical area.

During air combat sorties, the measured mean muscle strain is 5–20% of maximal voluntary contraction level (MVC), and it is highest in the cervical flexors (14). It has been reported that muscular strain in the cervical muscles is in the 40–80% MVC range under high G_z (4). Peak strain episodes often exceed MVC activity levels. The highest reported value has been 257% of MVC, which caused muscle damage and subsequent mission abort (14).

Helmet weight alone has been reported to increase muscle strain by 15% under high G_z (5) and aggravate fatigue in the cervical area (15,16). Ultimately, the increased weight of the helmet system combined with a high ejection seat acceleration results in increased neck compression force which may even exceed the established cadaver injury limits (2).

When using helmet-mounted devices, both the additional weight and the helmet system's shifted center of gravity have significant effects on cervical loading. Biomechanical calculations and modeling indicate that helmet-mounted devices increase the neck load substantially, and that center of gravity offset has significant effects on head-neck torques, contact forces, and neck flexion angles (11). The mean muscular activity in the cervical muscles from electromyography (EMG) was significantly higher with subjects wearing helmet and NVG, or helmet, NVG, and counterweight, when compared with the results obtained when they wore a helmet alone (20). Similar findings were reported by Knight (9), who demonstrated that measured EMG activity in the cervical flexors, and especially in the extensor muscles, increased with an increase in frontal load. These two studies also showed that neck posture and movements might be even more significant than the weight of the headgear in certain situations. These studies were carried out in a $+1\ G_z$ environment, however.

It has been documented that the extra mass of the helmet, shifted center of gravity, and enhanced head movements increase the workload of the cervical muscles and potentially lead to a greater incidence of $+G_z$ induced neck injuries (1,8,10,13). Studies that would actually present methods of reducing pilots' cervical loading are practically unavailable, but trampoline training has been considered a tool for creating a "G environment" for fighter pilots' physical training, and it seems to be a

---

From the Training Air Wing, Kauhava, Finland (R. Sovelius); the Finnish Institute of Occupational Health, Oulu, Finland (J. Oksa); the Centre of Military Medicine, Aero Medical Centre, Helsinki, Finland (H. Rintala); the School of Public Health, University of Tampere, and the Research Unit, Tampere University Hospital, Tampere, Finland (H. Huhtala); and the Finnish Air Force Headquarters, Tikkakoski, Finland (S. Siitonen).

This manuscript was received for review in May 2007. It was accepted for publication in December 2007.

Address reprint requests to: Roope Sovelius, Training Air Wing, P.O. Box 5, FIN-62201 Kauhava, Finland; roope.sovelius@mil.fi.

DOI: 10.3357/ASEM.2130.2008

suitable method of reducing in-flight muscle strain in the neck area (19). The purpose of trampoline training is to improve general motor skills and enhance muscle balance. It is not known, however, what kinds of muscular activity responses trampoline training may produce. The aim of this study was to quantify muscle strain in the cervical area under G loading during trampoline exercises under different head load conditions: without the helmet, with the helmet, and with the helmet and the NVG device.

METHODS

There were 14 Finnish Air Force pilot cadets who acted as volunteer test subjects. Their mean age was 21.5 ± 0.9 yr, height 178.3 ± 0.1 cm, weight 74.0 ± 8.2 kg, and body mass index (BMI) 23.2 ± 1.9 $kg \cdot m^{-2}$. The subjects were informed of the details of the experimental protocol. The study was approved by the Finnish Defense Forces Medical Research Register, Finnish Air Force Headquarters, which granted a Research License, and The Ethical Committee of the Central Finland Hospital District.

The subjects performed trampoline exercises including basic, hand and knee, and back bouncing runs of 30 s each with a 1-min break between the runs. Basic bouncing simulates low G_z loading with the head in the neutral position. This exercise, which loads the muscles in the neck region, was regarded as a warm-up before more strenuous exercises were commenced for straining the flexor and extensor muscle groups. During back bouncing, the subject bounces on his back, assisting bouncing with rhythmic movements of the arms and legs, while during hand and knee bouncing only hands and knees touch the trampoline during the contact phase. These exercises, respectively, load the cervical flexor and extensor muscles in particular. The subjects were asked to stabilize their head in the neutral position during all exercises to avoid whiplash-type movements due to impulsive loading. Although the head is maintained in the neutral position during the exercises, and the direction of loading is basically along the x-axis, back bouncing is considered to activate cervical flexor muscles in a similar pattern to that seen during rotation and/or lateral bending of the neck during a “check six” maneuver or equivalent (6,9). Similarly, hand and knee bouncing is considered to simulate situations like a pullup or head extension under $+G_z$.

Three sets were performed: without the helmet, with the helmet (Alpha, Helmets Ltd, Wheathampstead, UK; weight 1530 g), and with the helmet and NVG device (an authentic replica, shape and weight of the model used in the Finnish Air Force: F4949 F, ITT-Industries, Roanoke, VA; weight 800 g). The sets were performed in a random order. Bouncing without the helmet was considered a baseline.

During the exercises, the EMG activity of the right and left sternocleidomastoid (SCM), cervical (CES) and thoracic erector spinae (TES), and trapezoid (TRA) muscles was measured using bipolar surface electrodes. Five equal-height jumps carried out by each subject were chosen for the analysis. The exercises were video recorded, and the height of jumps was measured from a scale behind the trampoline. The measured EMG was compared with EMG obtained during isometric MVC. EMG levels as well as muscle strain were determined as a percent of MVC (%MVC). Muscle strain was measured using a portable eight-channel EMG device (ME3000P, Mega Electronics Ltd., Kuopio, Finland). Bipolar EMG recordings were obtained using pregelled surface electrodes (Medicotest M-OO-S, Olstykke, Denmark) placed longitudinally on the muscles 2 cm apart from each other (7). The ground electrodes were placed on inactive tissue. Measured signals were 1000 times preamplified. The signal band between 20 and 500 Hz was full-wave rectified and averaged with a 100-ms time constant.

On a separate occasion, vertical acceleration measurements ($N = 4$) during bouncing were performed with a MoTec ADL Datalogger and triple axis G-sensor (Printsport Oy, Lievestuore, Finland) mounted on the flying helmet. Vertical acceleration during bouncing varies between 0 and $+4$ G_z. All subjects achieved similar acceleration levels in all exercises, and despite minor differences in their mass and jump heights, the method was considered reliable for acceleration studies. In addition, the height of jumps was matched in the present study when measuring muscle strain during the exercises. Thus, intraindividual acceleration was considered identical. A 4.3-m diameter round trampoline (JumpKing, Inc., Portland, OR) was used.

Mean differences with 95% confidence intervals are given as descriptive statistics. A paired *t*-test was used to assess the differences for loading effects without and with the helmet, as well as between the helmet and the helmet with NVG device. The subjects acted as their own controls. In all tests, $P \leq 0.05$ was considered statistically significant.

RESULTS

When comparing bouncing without and with the helmet, the mean muscle strain (%MVC) during all exercises increased to a statistically significant extent in the SCM, CES, and TRA. The NVG device increased the strain in all muscles that were subject to measurements further, but less so. NVG-induced change in strain was statistically significant in the SCM and CES (**Table I**).

Muscular loading during every exercise was also analyzed separately (**Table II**). During basic bouncing, helmet-induced increase in muscle strain was statistically significant in the posterior muscles CES and TRA. Extra frontal weight, which resulted from the use of the NVG device, increased strain mostly in the SCM and TES, but this increase was not statistically significant. Back bouncing with the subjects wearing the helmet increased strain in the cervical muscles SCM and CES. NVG increased loading to a statistically significant extent in the SCM.

Baseline muscle strain was the lowest in all measured muscles during extensor loading; i.e., hand and knee bouncing compared to the other exercises. However, the helmet enhanced muscle strain in a statistically significant manner in all muscles except the TRA. NVG-induced

TABLE I. THE MEAN EFFECT OF THE HELMET AND NVG ON MUSCLE STRAIN (%MVC) IN ALL EXERCISES COMBINED.

	Baseline		Helmet				Helmet + NVG			
Muscle	%MVC	CI 95%	%MVC	CI 95%	ΔHEL (%)	P_{HEL}	%MVC	CI 95%	ΔNVG (%)	P_{NVG}
SCM	14.4	12.2 to 16.6	16.8	14.0 to 19.6	18.0	0.002	18.2	15.1 to 21.3	11.2	0.006
CES	19.7	16.8 to 22.6	25.1	20.8 to 29.4	28.2	< 0.001	26.2	21.6 to 30.8	5.9	0.043
TRA	16.7	12.7 to 18.9	18.6	14.2 to 23.0	18.1	0.002	18.5	14.2 to 22.8	4.7	0.485
TES	23.3	18.5 to 28.1	24.7	18.1 to 30.3	11.0	0.218	25.5	21.0 to 30.0	16.6	0.258

%MVC = proportional maximal voluntary contraction activity; CI 95% = 95% confidence intervals; ΔHEL = a mean of individual changes in %MVC (in percent) between loading with the baseline and helmet; ΔNVG = a mean of individual changes of %MVC (in percent) between loading with the helmet and helmet with NVG; P_{HEL} = significance of difference in %MVC values between the baseline and helmet; P_{NVG} = significance of difference in %MVC values between the helmet and NVG; SCM = sternocleidomastoids; CES = cervical erector spinae; TRA = trapezoids; TES = thoracic erector spinae.

extra loading was statistically significant in both the cervical and thoracic erector spinae muscles.

DISCUSSION

Helmet weight alone had the most significant effect on muscular workload, causing increased muscle strain under impulsive G_z forces in the SCM, CES, and TRA. Yet the extra frontal weight of the NVG device caused a further increase in cervical muscle strain, primarily in the SCM. It seems that the higher weight of the helmet has a more significant effect on cervical muscle loading than the lighter NVG, which causes a shift in the center of gravity.

NVG-induced increase in muscle strain was greatest in the muscles that were specifically loaded, such as the SCM in back bouncing, and the cervical extensors in hand and knee bouncing. Thus, extra frontal weight seems not to load all muscles evenly, and neither does it seem to subject certain muscles to particularly high loads. Instead, it appears to affect essentially those muscles that are already subjected to the highest loadings.

The frontally mounted NVG device adds an extra flexor moment to the neck, compounding the posterior neck extensors work in the control of head posture and movements. During basic bouncing, the EMG activity was higher in the thoracic muscles (TRA and TES) than in the cervical extensors, which may indicate in this case

TABLE II. MUSCLE STRAIN UNDER DIFFERENT CONDITIONS.

Basic Bouncing

	Baseline		Helmet				Helmet + NVG			
Muscle	%MVC	CI 95%	%MVC	CI 95%	ΔHEL (%)	P_{HEL}	%MVC	CI 95%	ΔNVG (%)	P_{NVG}
SCM	11.7	9.2 to 14.2	13.1	10.1 to 16.1	13.0	0.092	13.6	11.0 to 16.2	11.9	0.305
CES	19.6	15.3 to 23.9	22.9	18.1 to 27.7	18.7	0.005	22.4	18.3 to 26.5	1.6	0.325
TRA	25.1	16.2 to 34.0	28.0	18.4 to 37.6	12.0	0.010	27.0	18.4 to 35.6	3.6	0.359
TES	26.8	16.1 to 27.5	28.3	16.0 to 40.6	3.3	0.134	27.8	19.4 to 36.2	11.1	0.424

Back Bouncing

	Baseline		Helmet				Helmet + NVG			
Muscle	%MVC	CI 95%	%MVC	CI 95%	ΔHEL (%)	P_{HEL}	%MVC	CI 95%	ΔNVG (%)	P_{NVG}
SCM	21.0	16.9 to 25.1	23.8	18.5 to 29.1	14.2	0.037	27.1	21.1 to 33.1	13.5	<0.001
CES	21.0	14.0 to 28.0	24.9	15.1 to 34.7	18.7	0.042	24.9	15.3 to 34.5	2.4	0.469
TRA	14.7	10.2 to 19.2	15.8	10.3 to 21.3	12.9	0.149	16.7	9.9 to 23.5	4.4	0.340
TES	25.9	18.0 to 33.8	23.7	13.9 to 33.5	−0.5	0.328	22.2	16.7 to 27.7	10.3	0.313

Hand and Knee Bouncing

	Baseline		Helmet				Helmet + NVG			
Muscle	%MVC	CI 95%	%MVC	CI 95%	ΔHEL (%)	P_{HEL}	%MVC	CI 95%	ΔNVG (%)	P_{NVG}
SCM	10.8	8.9 to 12.7	14.1	9.7 to 18.5	26.6	0.039	14.6	10.5 to 18.7	8.5	0.305
CES	18.5	14.9 to 22.1	27.4	20.1 to 34.7	45.7	0.003	31.1	22.2 to 40.0	13.3	0.004
TRA	10.1	6.6 to 13.6	11.7	7.9 to 15.5	28.6	0.077	11.7	7.7 to 15.7	6.2	0.482
TES	17.5	12.0 to 23.0	22.0	15.1 to 28.9	28.5	0.025	26.9	18.0 to 35.8	27.5	0.025

%MVC = proportional maximal voluntary contraction activity; CI 95% = 95% confidence intervals; ΔHEL = a mean of individual changes in %MVC (in percent) between loading with the baseline and helmet; ΔNVG = a mean of individual changes in %MVC (in percent) between loading with the helmet and helmet with NVG; P_{HEL} = significance of difference of %MVC values between baseline and helmet; P_{NVG} = significance of difference of %MVC values between helmet and NVG; SCM = sternocleidomastoids; CES = cervical erector spinae; TRA = trapezoids; TES = thoracic erector spinae.

that the basic bouncing also considerably loads the thoracic muscles. However, in the present study the total workload seemed to increase most in the cervical muscles SCM and CES due to the NVG. This may result from the nature of the trampoline exercises loading specifically the flexor and extensor muscles (back bouncing and hand and knee bouncing). Additionally, the rapid acceleration onset rates encountered during trampoline exercises may cause some extra muscular activity in the cervical muscles as the subject strives to maintain the stability of the head.

The level of muscle activation recorded from the neck flexors and extensors in the present study was comparable with in-flight measurements performed in previous studies, and muscle strain measured during the specific trampoline exercises described above seems to be similar to muscle activation levels reported for different head postures during G_z in the cockpit (4,12). However, any comparison of different in-flight and test pattern results needs to be undertaken with care. Modern fighters are capable of sustaining 8–9 G_z with high onset rates, while trampoline exercises can simulate just a fraction of the first second up to $+4\ G_z$. The results of the present study must, therefore, not be considered analogous to data obtained in a real cockpit environment.

The limitation of the present study is that muscular activity during non-neutral head positions was simulated by specific muscle loadings, not with actual head movements or twisted head postures. The neutral position was considered less risky under impulsive loadings. Head movements and non-neutral head postures with NVG probably result in higher muscle strain during G_z loading than reported in the present study or literature. It has been established that head posture increases muscle strain in the cervical muscles more than the increased weight of helmet-mounted equipment (9,20). This finding is also supported by a study where in-flight muscle strain in different head positions was measured (4).

It has been reported that the overall neck muscle strength of pilots does not differ significantly from that of non-pilots, nor does exposure to $+G_z$ forces lead to specific changes in isometric muscle strength (3,18). On the contrary, it can be argued that the loading of muscles would cause neural and hypertrophic adaptations in the neuromuscular system, leading to enhanced muscular performance. Consideration should also be given to the fact that every training or measuring method is always site and intensity specific and generated forces vary a lot depending on the phase of range of movement (10,17,21). Hence, it might be possible that the training effect of G_z loading has not been observed in these studies due to a measuring method being insufficient to demonstrate the neuromuscular adaptations for specific loadings. Alternatively, loadings may have had negative effects on muscles, as muscles are not recovered from the loading, and thus they have performed optimally.

The trampoline is definitively not an analog training device for conditioning aircrews to exposures from G_z forces in the same manner as, say, the centrifuge is. However, as a device capable of inducing low-intensity, repetitive loadings, it may have a potential for the training of the cervical muscles to maintain the posture of the head during that important first second of G_z loading. The results of the present study demonstrate workloads of different muscles and may help to develop pilot training programs that would prepare pilots to counter high G_z loading.

Better muscle conditioning programs, enhanced muscle coordination, and head support strategies are all needed to prevent neck injuries stemming from the extra mass of the helmet. Helmet weight seems to induce more muscle strain than NVG, but helmet-mounted devices also have a significant effect on increased cervical loading. Trampoline training may have a positive effect from the occupational standpoint since it loads cervical muscles somewhat in a way similar to in-flight G_z forces, and it is, therefore, assumed to develop neuromuscular adaptation beneficially.

ACKNOWLEDGMENTS

The study was supported by a grant from the Work Environment Fund of the Ministry of Finance.

REFERENCES

1. Ashrafiuon H, Alem NM, McEntire BJ. Effects of weight and center of gravity location of head-supported devices on neck loading. Aviat Space Environ Med 1997; 68:915–22.
2. Buhrman JR, Perry CE. Human and manikin head/neck response to +Gz acceleration when encumbered by helmets of various weights. Aviat Space Environ Med 1994; 65:1086–90.
3. Burnett AF, Naumann FL, Burton EJ. Flight-training effect on the cervical muscle isometric strength of trainee pilots. Aviat Space Environ Med 2004; 75:611–5.
4. Green ND, Brown L. Head positioning and neck muscle activation during air combat. Aviat Space Environ Med 2004; 75:676–80.
5. Hamalainen O. Flight helmet weight, +Gz forces, and neck muscle strain. Aviat Space Environ Med 1993; 64:55–7.
6. Hamalainen O, Vanharanta H. Effect of Gz forces and head movements on cervical erector spinae muscle strain. Aviat Space Environ Med 1992; 63:709–16.
7. Hermens HJ, Freriks B, Merletti R, Stegeman DF, Blok J, Rau G, et al. European recommendations for surface electromyography. Enschede, the Netherlands: Roessingh Research and Development; 1999.
8. Hoek van Dijke GA, Snijders CJ, Roosch ER, Burgers PI. Analysis of biomechanical and ergonomic aspects of the cervical spine in F-16 flight situations. J Biomech 1993; 26:1017–25.
9. Knight JF, Baber C. Neck muscle activity and perceived pain and discomfort due to variations of head load and posture. Aviat Space Environ Med 2004; 75:123–31.
10. Kumar S, Narayan Y, Amell T, Ferrari R. Electromyography of superficial cervical muscles with exertion in the sagittal, coronal and oblique planes. Eur Spine J 2002; 11:27–37.
11. Lee CM, Freivalds A, Lee SY. Biodynamic simulations of the effect of a neck-mounted air bag on the head/neck response during high G acceleration. Aviat Space Environ Med 1991; 62:747–53.
12. Netto KJ, Burnett AF. Neck muscle activation and head postures in common high performance aerial combat maneuvers. Aviat Space Environ Med 2006; 77:1049–55.
13. Newman DG. Helmet-mounted equipment in the high +Gz environment. Aviat Space Environ Med 2002; 73:730–1.
14. Oksa J, Hamalainen O, Rissanen S, Myllyniemi J, Kuronen P. Muscle strain during aerial combat maneuvering exercise. Aviat Space Environ Med 1996; 67:1138–43.
15. Phillips CA, Petrofsky JS. Neck muscle loading and fatigue: systematic variation of headgear weight and center-of-gravity. Aviat Space Environ Med 1983; 54:901–5.
16. Phillips CA, Petrofsky JS. Quantitative electromyography: response of the neck muscles to conventional helmet loading. Aviat Space Environ Med 1983; 54:452–7.

17. Seng KY, Lee Peter VS, Lam PM. Neck muscle strength across the sagittal and coronal planes: an isometric study. Clin Biomech (Bristol, Avon) 2002; 17:545–7.
18. Seng KY, Lam PM, Lee VS. Acceleration effects on neck muscle strength: pilots vs. non-pilots. Aviat Space Environ Med 2003; 74:164–8.
19. Sovelius R, Oksa J, Rintala H, Huhtala H, Ylinen J, Siitonen S. Trampoline exercise vs. strength training to reduce neck strain in fighter pilots. Aviat Space Environ Med 2006; 77:20–5.
20. Thuresson M, Ang B, Linder J, Harms-Ringdahl K. Neck muscle activity in helicopter pilots: effect of position and helmet-mounted equipment. Aviat Space Environ Med 2003; 74:527–32.
21. Ylinen J, Nuorala S, Hakkinen K, Kautiainen H, Hakkinen A. Axial neck rotation strength in neutral and prerotated postures. Clin Biomech (Bristol, Avon) 2003; 18:467–72.

Neck and Back Muscle Loading in Pilots Flying High G_z Sorties With and Without Lumbar Support

Roope Sovelius, Juha Oksa, Harri Rintala, and
Simo Siitonen

Sovelius R, Oksa J, Rintala H, Siitonen S. ***Neck and back muscle loading in pilots flying high G_z sorties with and without lumbar support.*** **Aviat Space Environ Med 2008; 79:616–9.**

Introduction: Fighter pilots frequently encounter neck and back pain and injuries due to high G_z loading. A lumbar support could diminish muscle strain in the lower back under G_z loading and might also have a positive effect on cervical muscle strain, due to a more ergonomic sitting posture. The aim of this study was to determine the effects of individually adjusted lumbar supports on fighter pilots' neck and back muscle loadings. ***Methods:*** There were 11 Finnish Air Force pilots who acted as test subjects. They flew two basic air combat maneuvering sorties with and without the LS. The EMG activity of the sternocleidomastoid (SCM), cervical (CES), thoracic (TES), and lumbar erector spinae muscles (LES) were measured during these sorties, and the number and duration of EMG gaps was analyzed. Subjective experiences about the lumbar support were evaluated using a questionnaire. ***Results:*** In all measured muscles, mean percent maximal voluntary contraction (%MVC) was lower when the LS was used, yet these changes were not statistically significant. Individual differences in %MVC between flights diminished in the CES (9%), TES (7%), and LES (8%) with LS in use. There was also a tendency toward increased number of gaps in EMG activity when flying with the LS. According to questionnaire responses, the LS seems to relieve in-flight symptoms and reduce the fatigue in the lower back muscles. Not all subjects benefited from the LS, however. ***Conclusion:*** There seems to be a tendency toward a lower muscle strain with the LS, but there are considerable individual differences.

Keywords: sitting posture, ergonomics, muscular loading, hypergravity.

PILOTS OF HIGH-performance fighters frequently report work-related neck and back pain. High-G_z maneuvering causes fatigue, especially in the neck, but also in the lower back muscles (13). Fatigued muscles are more vulnerable to acute injuries, and they are not able to support the spinal column as effectively as unfatigued muscles. The cumulative number of flight hours has been identified as a significant determinant of acute in-flight musculoskeletal symptoms (3,5). It has also been reported that the frequent exposure to high $+G_z$ forces causes premature disk degeneration in the cervical spine (4). Although similar effects of lumbar degeneration have been suggested, ageing seems to be a more significant determinant than G_z loading (11,14).

Sitting postures and ejection seat angles need also be addressed when considering pilots' musculoskeletal loadings under hypergravitational forces. A review article suggested that subjects sitting on car seats with backrest inclinations of 110° to 130° and wearing a concomitant lumbar support are subjected to the lowest intervertebral disc pressures and show the lowest electromyography (EMG) recordings from the spinal muscles (7). This finding was supported by clinical outcome from another car-driver study, where the prevalence of low back pain was five times greater among those with back-thigh angle lower than 86° compared to those with a back-thigh angle greater than 91° (2). However, an increase in the backrest angle has only a minor effect on lumbar lordosis (1). On the other hand, the more backward inclined (120°) backrest of the F-16 seat decreases the lordosis of the cervical spine (9), which in turn increases compressive forces and intervertebral disc pressure (6). It has been determined that this has a bearing on the high incidence of cervical disorders among F-16 pilots (8,10).

Since 1973, all British Royal Air Force aircrew who suffer from pain in the lower back had the opportunity of being issued lumbar support. Fast jet (Tornado, Jaguar, Harrier, Hawk) pilots have also received these supports. Most (73%) of the lumbar support users are rotary wing pilots of different services, however (17). It has been reported that the lumbar support enhances the effectiveness of muscular work during the anti-G straining maneuver (AGSM). This has been explained by the torso muscles being at a more optimal length due to the more upright posture of the spine, which in turn enhances force production ability during the AGSM. (12)

According to Finland Aero Medical Centre's follow-up and its survey directed to all fighter pilots, occupational neck and back disorders are most often related with Hawk jet flight training and the sitting posture in the Hawk's ejection seat (unpublished observations, 2006). This may be partly due to the nature of jet flight training (air combat maneuvering, tactical jet training); it includes high flying intensity with frequent periods of

---

From the Training Air Wing, Kauhava, Finland (R. Sovelius); the Finnish Institute of Occupational Health, Oulu, Finland (J. Oksa); the Centre of Military Medicine, Aero Medical Centre, Helsinki, Finland (H. Rintala); and the Finnish Air Force Headquarters, Tikkakoski, Finland (S. Siitonen).

This manuscript was received for review in December 2007. It was accepted for publication in February 2008.

Address reprint requests to: Roope Sovelius, Training Air Wing, P.O. Box 5, FIN-62201 Kauhava, Finland; roope.sovelius@mil.fi.

DOI: 10.3357/ASEM.2250.2008

sustained G_z loading with high peak values, causing musculoskeletal symptoms. However, if the seat fails to support the lower back adequately, the pilot will slump into the seat under high G_z and lumbar lordosis decreases. This results in a forward inclined upper torso posture, which in turn is compensated by the extension of the cervical spine in order to maintain an optimal eye position in the cockpit. It is hypothesized that the lumbar support could diminish muscle strain in the lower back under G_z loading and might also have a positive effect on cervical muscle strain, both due to the more ergonomic sitting posture that the support enables. The aim of this study was to determine the effects of individually adjusted lumbar supports on fighter pilots' neck and back muscle strain.

METHODS

There were 11 Finnish Air Force pilots who acted as test subjects. Their mean height was 179 ± 5 cm, weight 77 ± 8 kg, and body mass index 24 ± 2 $kg \cdot m^{-2}$. The subjects had no history of noteworthy spinal complaints, but they all had experienced some musculoskeletal symptoms related to flying during their career. As EMG analysis was not completed on three subjects due to technical problems, their recordings were excluded from the muscular activity analyses. The subjects were informed of the details of the experimental protocol. The Finnish Defense Forces Medical Research Register, the Finnish Air Force Headquarters, which granted a research license, and The Ethical Committee of the Central Finland Hospital District, approved this study.

The subjects flew two basic air combat maneuvering sorties with and without the lumbar support in a random order. The platform during these sorties was the BAe Systems Hawk MK51 fitted with a Martin-Baker Mk 10L seat with 107° inclination in backrest and 94.5° thigh-back angle. The flights were similar training sorties and consisted of aerobatics and basic tactical maneuvering. They were performed according to sortie charts where the sequence of maneuvers and associated parameters (e.g., $v_{i,}$ G_z, etc.) were laid down in detail. The number of times the levels of +0.25, +2.5, +3.5, +4.5, +5.5, +7.0, and +8.0 G_z were exceeded during the sorties was recorded by the aircraft's accelerometer.

The individually shaped lumbar support consisted of a slightly compressible Plastazote® polyethylene foam pad and an elastic band (80% polyester and 20% elastan). Its thickness varied from approximately 7 to 15 mm. The support was not designed to push the lumbar spine forward to change the posture; its purpose was to fill the gap formed by the lumbar lordosis between the back and seat. Before the final configuration of each lumbar support was determined, the support was test-sat in a Hawk seat, and the thickness or size of the support was altered based on each subject's opinion, if required. The support was placed underneath the flight suit.

During the sorties, the EMG activity of the right and left sternocleidomastoid (SCM), cervical (CES), thoracic (TES), and lumbar erector spinae muscles (LES) was measured using bipolar surface electrodes. Measured EMG was compared with EMG recorded during maximal voluntary contraction (MVC), and EMG level and muscle strain were determined as a percentage of MVC (%MVC). Muscular activity was determined using a portable eight-channel EMG device (ME3000P, Mega Electronics Ltd., Kuopio, Finland). Bipolar EMG recordings were obtained using pregelled surface electrodes (Medicotest M-OO-S, Olstykke, Denmark) placed longitudinally on muscles with a distance of 2 cm between their measurement surfaces. Ground electrodes were placed on inactive tissues. EMG signals from the skin above working muscles were acquired at a sample rate of 100 Hz. The measured signal was preamplified 2000 times, and the signal band between 20 and 500 Hz was full-wave rectified and averaged with a 100 ms time constant. Short interruptions ("silent periods") of less than 10 μV for at least 300 ms in EMG activity were considered EMG gaps, and their number and duration were analyzed. A modified Winfield's questionnaire (17) was used to determine the displacement of the lumbar support along with its effect on sitting posture, neck and lower back fatigue, and ability to control the aircraft. A visual analogue scale (VAS) was used to quantify the subjectively experienced in-flight musculoskeletal symptoms and muscular fatigue.

Mean differences with 95% confidence intervals (CI) are given as descriptive statistics. A paired *t*-test was used to assess the differences of G_z-loadings between the test flights and the effects of loading with and without the lumbar support. Test subjects acted as their own controls. In all tests, $P \leq 0.05$ was considered statistically significant.

RESULTS

Comparison of $+G_z$ loading during the test flights is shown in **Fig. 1**. There were no differences in $+G_z$ loadings between flight with and without the lumbar support ($P = 0.34$). In all measured muscles, mean %MVC was lower when the lumbar support was used. Individual differences in %MVC between flights diminished in CES, TES, and LES muscles (**Table I**).

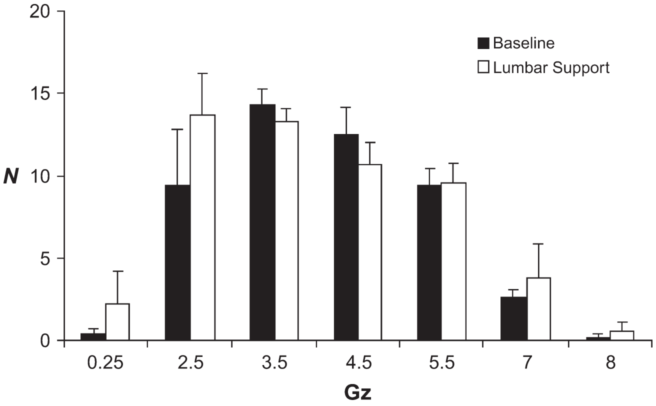


Fig. 1. G_z loading during the test flights. The aircraft's accelerometer recorded the number of times the given Gs were exceeded.

TABLE I. MUSCLE STRAIN DURING TEST FLIGHTS WITH AND WITHOUT THE LUMBAR SUPPORT.

	Baseline		Lumbar Support		Change (%)		
Muscle	%MVC	CI 95%	%MVC	CI 95%	Δ %MVC	CI 95%	*P*
SCM	24.3	17.1 to 31.5	23.9	17.0 to 30.8	4.0	−19.7 to 27.7	0.844
CES	39.2	23.1 to 55.3	36.8	25.4 to 48.2	−9.3	−20.6 to 2.0	0.493
TES	24.7	18.7 to 30.7	24.1	16.7 to 31.5	−7.2	−25.8 to 11.4	0.771
LES	22.1	16.9 to 27.3	20.2	14.4 to 27.0	−7.5	−31.4 to 16.4	0.367

The flight without the support was used as a baseline.
%MVC = proportional maximal voluntary contraction activity; Δ %MVC = a mean of individual changes in %MVC (in percent) between the test flights; SCM = sternocleidomastoids; CES = cervical erector spinae; TES = thoracic erector spinae; LES = lumbar erector spinae.

The deviation between subjects was wide, however, and change in muscle strain was not statistically significant in any measured muscle. Some subjects benefited from the support, while others experienced an opposite effect, at least in some muscles.

There was also a tendency toward an increased number of EMG gaps when flying with the lumbar support (**Table II**). The change was negative only in CES. Nevertheless, the changes in muscle activity were not statistically significant. The duration of the gaps shortened by 19% (CI 95%: 6–32%; *P* = 0.004) in the SCM with the support, otherwise there was no change in gap duration.

Displacements of the lumbar support were not reported. Five subjects stated that the support improved sitting comfort, five noticed no changes, and one reported reduced sitting comfort compared with normal, i.e., baseline flight without lumbar support. Musculoskeletal symptoms during flights with the support diminished by 25% (CI 95% 14–36%, *P* = 0.002) according to the VAS responses. One subject reported less fatigue in the neck muscles, while three subjects reported a less fatigued lower back when flying with the support. Fatigue experienced by the subjects as quantified by the VAS diminished by 3% (CI 95%: 0–6%, *P* = 0.14) in neck muscles, and by 10% (CI 95%: 1–19%, *P* = 0.67) in the lower back. Reported symptoms or fatigue during flights did not correlate with measured muscle strain (%MVC) or EMG gaps.

DISCUSSION

The results of this study indicate that there seems to be a tendency toward a lower muscle strain and increased number of EMG gaps when the lumbar support is worn. The pilots' subjective experiences were predominantly positive after flights with the support. Changes in muscle strain in the CES, TES, and LES may have physiological significance despite lack of statistical power in this study. Reduced muscle strain may correspond to less fatigued muscles during G_z loading, and this in turn helps achieve a better muscular performance. Slightly positive changes in the lower muscles, LES and TES, may indicate a more efficacious working of the muscles, perhaps due to a better posture and more optimal length of the lower back muscles. Consistent with having a beneficial effect on muscle strain in the cervical extensors (CES), the lumbar support may also have beneficial effects on cervical posture. However, due to lack of definite documentation of postures, this remains a speculation.

There was a tendency toward a slight increase in the number of EMG gaps when the lumbar support was being worn. The duration of the EMG gaps did not changed significantly, only the gaps in the SCM were shorter, but conversely it seemed likely that the number of gaps in SCM increases when wearing the support. The measurements obtained showed wide variation between subjects in all muscles, however. EMG gaps have been linked to reduced muscle loading; conversely, the absence of gaps is associated with a higher incidence of symptoms (15,16). The support was aimed to fill the space between the back and seat formed by lordosis, and it is thought that it prevents the lower back slumping into the seat, and this anatomically better posture is suggested also to contribute to the small increase in the number of EMG gaps.

As all subjects were experienced pilots, their neuromuscular system is to some extent adapted to sitting on an ejection seat during high G_z loading. The single sortie

TABLE II. THE NUMBER OF EMG GAPS AND THEIR CHANGE DURING FLIGHTS.

	Baseline		Lumbar Support		Change (%)		
Muscle	Gaps/min	CI 95%	Gaps/min	CI 95%	Δ Gaps	CI 95%	*P*
SCM	31.6	21.4 to 41.8	32.9	23.2 to 42.6	13.1	−25.4 to 51.6	0.761
CES	39.5	23.5 to 55.5	38.5	28.1 to 48.9	−3.5	−28.4 to 21.4	0.802
TES	44.6	32.0 to 57.2	43.9	31.4 to 56.4	18.7	−61.5 to 98.9	0.850
LES	44.6	29.8 to 59.4	48.1	31.2 to 65.0	14.5	−16.6 to 45.6	0.421

The flight without the support as a baseline.
Δ Gaps = a mean of individual changes in the rate of EMG gaps (in percent) between the test flights; SCM = sternocleidomastoids; CES = cervical erector spinae; TES = thoracic erector spinae; LES = lumbar erector spinae.

with exposure to the lumbar support in his study may disrupt this adapted state, and probably represents a transient "disturbed" phase. Therefore, it is reasonable to expect that the results would be different if the subjects were tested after an extended period (e.g., months) and the support might have a more consistent and beneficial effect.

Apart from reducing muscular strain the lumbar support may prevent in-flight pain and fatigue in another way. As it has been reported to enhance the effectiveness of muscular work during the AGSM due to enhanced force production of the torso muscles (12), increased intra-abdominal pressure created by a more effective AGSM could increase the support to the spinal structures, which would then lower the risk of back injuries during exposure to high G_z forces.

On the other hand, pilots flying modern fighter aircraft (like the F-18 in the Finnish Air Force) do not need to perform AGSMs to avoid G_z-induced loss of consciousness due to the use of advanced G suits and positive pressure breathing that improves G tolerance effectively. Authors suppose this relaxed sitting during G_z loading may result in lesions in the lower back due to inadequate support by paravertebral muscular tone and intra-abdominal pressure. This theory is supported by the increased number of F-18 pilots' flight-related lumbar symptoms (Finland Aero Medical Centre's follow-up, unpublished observation, 2006). Further studies are needed to prove or disprove this theory.

According to the questionnaire responses, the lumbar support seems to relieve in-flight symptoms, reduce fatigue of the lower back muscle, and improve the sitting posture in some individuals. There was a lack of correlation between EMG findings and fatigue symptoms, however. The disturbed adaptation described above may be the reason for this correlation, but on the other hand, this indicates the need for objective measurements parallel with subjective questionnaires. The changes in strain may be also negative, despite positive subjective feeling, especially as the responses obtained were based on a single flight wearing the support. A longer test period would be needed to evaluate individual changes in symptoms and fatigue as well as possible new loading effects induced by the support. Who should use the support remains, therefore, to be discussed. In practice, this means that the effects of the support would need to be tested individually.

It is concluded that the lumbar support may diminish pilots' muscle strain. Some individuals may benefit from the support greatly owing to the decreased muscular loading that it provides, yet others may experience opposite effects. Thus, it is essential that flight surgeons assess the need and benefit of the support for each individual.

ACKNOWLEDGMENTS

This study was supported by grant from the Work Environment Fund of the Ministry of Finance. The authors are grateful to Pasi Luoma-aho, Sr.Ltn., and Teemu Elonen, Sr.Ltn., Finnish Air Force, for their contribution to making this research possible. Ms. Heini Huhtala, M.Sc., University of Tampere, Finland, is acknowledged for the statistical guidance she provided.

REFERENCES

1. Andersson GB, Murphy RW, Ortengren R, Nachemson AL. The influence of backrest inclination and lumbar support on lumbar lordosis. Spine 1979; 4:52–8.
2. Chen JC, Dennerlein JT, Chang CC, Chang WR, Christiani DC. Seat inclination, use of lumbar support and low-back pain of taxi drivers. Scand J Work Environ Health 2005; 31:258–65.
3. Hamalainen O. Thoracolumbar pain among fighter pilots. Mil Med 1999; 164:595–6.
4. Hamalainen O, Vanharanta H, Kuusela T. Degeneration of cervical intervertebral disks in fighter pilots frequently exposed to high +Gz forces. Aviat Space Environ Med 1993; 64:692–6.
5. Hamalainen O, Vanharanta H, Bloigu R. +Gz-related neck pain: a follow-up study. Aviat Space Environ Med 1994; 65:16–8.
6. Harms-Ringdahl K, Ekholm J, Schuldt K, Nemeth G, Arborelius UP. Load moments and myoelectric activity when the cervical spine is held in full flexion and extension. Ergonomics 1986; 29:1539–52.
7. Harrison DD, Harrison SO, Croft AC, Harrison DE, Troyanovich SJ. Sitting biomechanics part I: review of the literature. J Manipulative Physiol Ther 1999; 22:594–609.
8. Hendriksen IJ, Holewijn M. Degenerative changes of the spine of fighter pilots of the Royal Netherlands Air Force (RNLAF). Aviat Space Environ Med 1999; 70:1057–63.
9. Hoek van Dijke GA, Snijders CJ, Roosch ER, Burgers PI. Analysis of biomechanical and ergonomic aspects of the cervical spine in F-16 flight situations. J Biomech 1993; 26:1017–25.
10. Jones JA, Hart SF, Baskin DS, Effenhauser R, Johnson SL, Novas MA, et al. Human and behavioral factors contributing to spine-based neurological cockpit injuries in pilots of high-performance aircraft: recommendations for management and prevention. Mil Med 2000; 165:6–12.
11. Landau DA, Chapnick L, Yoffe N, Azaria B, Goldstein L, Atar E. Cervical and lumbar MRI findings in aviators as a function of aircraft type. Aviat Space Environ Med 2006; 77:1158–61.
12. Oksa J, Linja T, Rintala H. The effect of lumbar support on the effectiveness of anti-G straining manuevers. Aviat Space Environ Med 2003; 74:886–90.
13. Oksa J, Hamalainen O, Rissanen S, Salminen M, Kuronen P. Muscle fatigue caused by repeated aerial combat maneuvering exercises. Aviat Space Environ Med 1999; 70:556–60.
14. Petren-Mallmin M, Linder J. Cervical spine degeneration in fighter pilots and controls: a 5-yr follow-up study. Aviat Space Environ Med 2001; 72:443–6.
15. Sjogaard G, Sogaard K. Muscle injury in repetitive motion disorders. Clin Orthop Relat Res 1998;21–31.
16. Veiersted KB, Westgaard RH, Andersen P. Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. Scand J Work Environ Health 1993; 19:284–90.
17. Winfield DA. Aircrew lumbar supports: an update. Aviat Space Environ Med 1999; 70:321–4.

Trampoline Exercise vs. Strength Training to Reduce Neck Strain in Fighter Pilots

Roope Sovelius, Juha Oksa, Harri Rintala,
Heini Huhtala, Jari Ylinen, and Simo Siitonen

Sovelius R, Oksa J, Rintala H, Huhtala H, Ylinen J, Siitonen S. ***Trampoline exercise vs. strength training to reduce neck strain in fighter pilots.*** **Aviat Space Environ Med 2006; 77:20–5.**

Introduction: Fighter pilots' muscular strength and endurance are subjected to very high demands. Pilots' fatigued muscles are at higher risk for injuries. The purpose of this study was to compare the effects of two different training methods in reducing muscular loading during in-flight and cervical loading testing (CLT). ***Methods:*** There were 16 volunteer Finnish Air Force cadets who were divided into 2 groups: a strength training group (STG) and a trampoline training group (TTG). During the 6-wk training period, the STG performed dynamic flexion and extension and isometric rotation exercises, and the TTG performed trampoline bouncing exercises. During in-flight and CLT, muscle strain from the sternocleidomastoid, cervical erector spinae, trapezius, and thoracic erector spinae muscles was recorded with EMG. ***Results:*** In-flight muscle strain in the STG after the training period decreased in the sternocleidomastoid 50%, cervical erector spinae 3%, trapezius 4%, and thoracic erector spinae 8%. In the TTG, the decrease was 41%, 30%, 20%, and 6%, respectively. In CLT, the results were similar. After a 3-mo follow-up period with intensive high $+G_z$ flying, EMG during CLT was still lower than in baseline measurements. ***Conclusion:*** Both training methods were found to be effective in reducing muscle strain during in-flight and CLT, especially in the cervical muscles. There was no statistically significant difference between the training groups. Introduced exercises expand muscles' capacities in different ways and the authors recommend both strength and trampoline training programs to be included in fighter pilots' physical education programs.

Keywords: trampoline, strength training, $+G_z$ loading, neck injury prevention, neck injuries.

THE MANEUVERABILITY of a modern high performance combat aircraft may exceed the pilot's capabilities to tolerate high $+G_z$ acceleration. High $+G_z$ load with high onset rate may produce neck pain and more serious injuries (11). Especially in the lateral neck, peak strain with magnitude well above the maximal voluntary contraction has been measured, thus presenting a potential risk for negative health effects and injuries (19). The level of peak strain episodes means that fighter pilots' muscular strength and endurance, particularly in the neck and shoulder area, are subjected to demands clearly higher than those of the average population. When sorties are repeated several times per day, aerial combat maneuvering exercises cause fatigue, especially in the neck muscles (20). Fatigued muscles perform with less power, leading to increased strain under equivalent loading, which may in turn increase the risk for neck injuries.

Individual factors affecting the pilot's muscle $+G_z$ load tolerance include strength and motor skill. It has been reported in the literature that increased muscle strength may reduce muscle strain under $+G_z$ loading (2,6,7) and thus diminish the incidence of acute in-flight neck pain (10,13,18). Portero (21) reported the beneficial effect of a strength-training program which increases neck muscle size and strength during lateral flexion, and decreases the fatigability of the superficial muscles of the neck. The training effects were evaluated in their study in three ways: strength; muscles' cross-sectional area in computerized tomography; and fatigability evaluated with a decrease in mean power frequency of the electromyogram.

Trampoline training has been considered as a tool to create a "G environment" for fighter pilots' physical training. The purpose of trampoline training is to improve general motor skills and to enhance muscle balance. However, as relatively low-intensity, repetitive muscular loading, it has the potential to improve muscle tone and endurance. Muscular fatigue and post-exercise muscular soreness in the neck/shoulder, foreneck, and abdominal area have also been reported when we evaluated users' experiences with this new training method.

The aim of this study was to compare two different training methods for reducing fighter pilots' neck strain under $+G_z$ loading and to evaluate how permanent the possible effects of the training methods were after a 3-mo follow-up. The question was: is it more efficient to do exercises that increase the general muscle strength or those that improve motor skill and muscle balance?

From the Training Air Wing, Finnish Air Force, Kauhava (R. Sovelius); the Oulu Regional Institute of Occupational Health, Oulu (J. Oksa); Finnish Air Force Headquarters, Tikkakoski (H. Rintala, S. Siitonen); the School of Public Health, University of Tampere (H. Huhtala); and the Department of Physical and Rehabilitation Medicine, Central Hospital, Jyväskylä (J. Ylinen); Finland.

This manuscript was received for review in July 2005. It was accepted for publication in October 2005.

Address reprint requests to: Roope Sovelius, Training Air Wing, P.O. Box 5, FIN-62201 Kauhava, Finland; roope.sovelius@mil.fi.

METHODS

Materials

There were 16 volunteer Finnish Air Force cadets who were divided into 2 groups: a strength training group (STG) and a trampoline training group (TTG). Mean age was 22.1 ± 0.6 yr in the STG and 22.6 ± 0.9 yr in the TTG, height 178.5 ± 4.6 cm and 177.5 ± 4.9 cm, weight 77.4 ± 6.5 kg and 76.3 ± 6.8 kg, and body mass index 24.3 ± 1.1 kg · m^{-2} and 24.2 ± 1.5 kg · m^{-2}, respectively. The subjects were informed of the details of the experimental protocol and the study was granted approval by the Finnish Defense Force Medical Research Register, the Finnish Air Force Headquarters Research License, and the Ethical Committee of Central Finland Hospital District.

The program was part of the cadets' physical training program. Prior to starting the training period all subjects took part in an introduction phase when training methods and exercises were practiced to ensure that all subjects had appropriate skills when the actual training was performed. The training program lasted for 6 wk and consisted of 2–3 exercise sessions per week. Training assessments were held to evaluate the successfulness of the training program. The STG did cervical dynamic flexion and extension exercises and isometric rotation exercises. Each training session consisted of 2–4 sets of each exercise. Sets were 20–40 reps with the resistance of approximately 15–30% of the measured maximal isometric force in the neutral position. Reps and resistance were increased progressively in each successive training week. The program consisted of two 3-wk periods of easy, moderate, and hard training weeks. Endurance type, relatively low exercise intensity was chosen to achieve increased endurance strength of the muscle groups exercised and to avoid over-training or cervical discomfort caused by too heavy loading.

The trampoline training program consisted of basic trampoline exercises including basic, hand and knee, and back bouncing. A round trampoline with a diameter of 4.3 m (JumpKing, Inc., Portland, OR) was used. Exercises were performed up to subjectively evaluated fatigue, normally in 30–60 s in one set, and there were similar 30–60-s recovery times between the sets. In the beginning of the training period, the set was performed twice, and after 2 wk, it was repeated three times. On a separate occasion, vertical acceleration measurements (n = 4) during bouncing were performed with a MoTec ADL Datalogger and triple axis G-sensor (Printsport Oy, Lievestuore, Finland) fixed to the flying helmet.

All subjects flew test flights with a BAe Hawk MK 51 jet trainer at the beginning and on completion of the training period. The flights were similar training sorties and consisted of aerobatics and basic tactical maneuvering. They were performed according to the sortie charts where the order of maneuvering and their performance values (e.g., v_i, G_z, etc.) were stated completely. The number of times the levels of +0.25, +2.5, +3.5, +4.5, +5.5, and +7.0 G_z were exceeded during the flight was recorded by the aircraft's G_z-meter coder.

In addition to in-flight measurements, muscle strain was also measured during a cervical loading test (CLT). In this test, cervical flexor and extensor muscles were loaded separately. Lateral loads were not tested due to a higher injury risk since a loaded vertebral column and muscles have less range of movement in that direction. Each neck movement, or strain against a load, involves multiple muscles working together, and the same muscle is participating in various different types of movement. Thus all muscles involved in anterior flexion movement or in straining against a posterior load have been considered flexors and all muscles involved in extension or strain against an anterior load have been considered extensors. In the test, each subject lay supine on the test table with shoulders on the edge of the test table wearing a helmet with an external load hanging on an 8-cm long elastic rope. The load for each subject was 25% of the maximal cervical extension force and 10% of the maximal cervical flexion force. The load was dropped from the frontal level (extensors) or from the occipital level (flexors) 15 times. The rope stretched approximately 6 cm when the load was dropped, and it incurred impact loading on the muscle group involved. The test was also performed 3 mo later (during a follow-up period) after a period of intensive flight training with high +G_z loading. The purpose of using the CLT was to exclude the effect of learning and improved

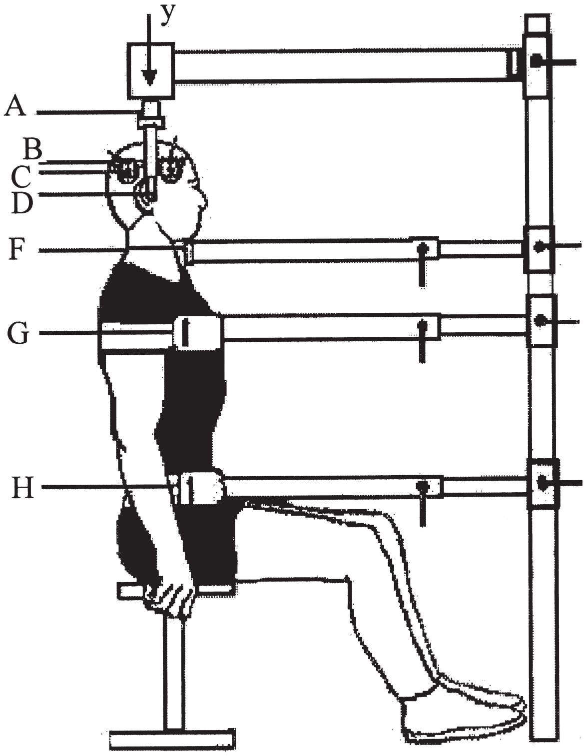


Fig. 1. The subject is seated in a standard position. The head is automatically centralized by tightening the pads (C) simultaneously from both sides by a screw system traveling the same distance, so that the sagittal plane comes into the middle. The frontal plane along the rotation axis of the apparatus (y) is verified to run through the opening of both ear canals by two sights (D). The pads can be moved (B) for comfort on the skull. The cheek is supported (F) to prevent head movement. The chest (G) and waist (H) are tightly fixed to the bars with wide straps at the level of the iliac spine and above the lower border of the scapula. Rotational forces are recorded from the load cell of the device (A). The load cell (F) is moved upwards and placed against the forehead with the lower edge located midway between the inner canthus of both eyes to measure neck flexion force.

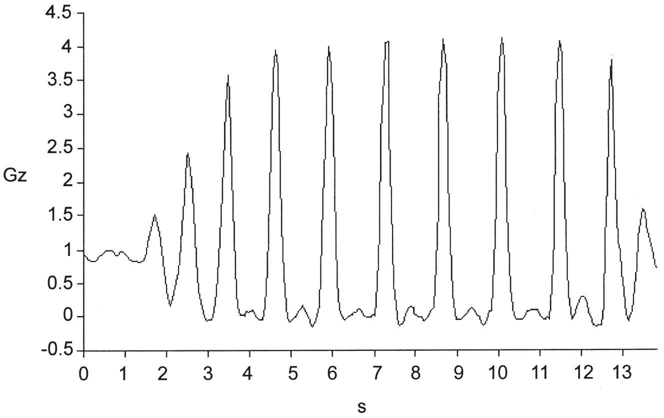


Fig. 2. Vertical acceleration during basic trampoline bouncing.

flying skills during the training period and follow-up. One subject had an in-flight neck injury prior to the scheduled test day, another was rejected from flight training during follow-up, and these two did not perform the follow-up measurements.

During the test flights and CLT, EMG activity of the right and left sternocleidomastoid, cervical and thoracic erector spinae, and trapezius muscles were measured using bipolar surface electrodes. Measured EMG was proportional to maximal voluntary contraction (MVC) EMG level and muscle strain was determined as a percent of MVC (%MVC). Muscle strain was determined using a portable eight-channel EMG device (ME3000P, Mega Electronics Ltd., Kuopio, Finland).

The bipolar EMG recordings were made using pregelled surface electrodes (Medicotest M-OO-S, Olstykke, Denmark). The electrodes were placed longitudinally on the muscles; the distance between the measurement surfaces of the electrodes was 2 cm. The ground electrodes were placed on inactive tissue. The measured signal was preamplified 1000 times. The signal-band between 20 and 500 Hz was full-wave rectified and averaged with a 100-ms time constant. The sites of the electrodes were marked on a clear plastic film with the aid of anatomical marks (moles, scars, etc.), thus ensuring that the electrodes were replaced in exactly the same place after the training period and for follow-up measurements.

The muscle strength of the cervical flexor, extensor, and rotator muscles was measured with an isometric neck strength measurement system (INSMS, Kuntoväline Oy, Finland) (25) before and after the training period (pre- and post-test). The subject was seated facing toward the apparatus while testing rotation and flexion forces (**Fig. 1**). While testing extension forces the subject was seated facing away from the apparatus. The load-cell was placed against the occipital at the same height as it was while measuring flexion force. After warm-up, the subject was asked to push/turn with maximal force three times in each direction with a pause of 45 s between each effort. The best one of three efforts was chosen for data analysis.

Statistics

Mean differences with 95% CI are given as descriptive statistics. A *t*-test was used to compare in-flight $+G_z$ loads between training groups or Flight 1 and Flight 2. ANOVA with repeated measures were used to determine training effects, i.e., muscle strain after the training period and between training groups. In all tests, $p < 0.05$ was considered statistically significant.

RESULTS

Vertical acceleration during basic trampoline bouncing varied between 0 and +4 G_z. A sample of the acceleration curve as a function of time is shown in **Fig. 2**. Comparison of $+G_z$ loading during the test flights is shown in **Fig. 3**. $+G_z$ loading was similar between training groups ($p = 0.21$) and between flights in the beginning and on completion of the training period ($p = 0.23$).

Maximal muscle force was increased in both groups in all measured directions after the training period. All test subjects enhanced their flexion and extension forces during the training period. Improvement in flexion force was significantly better in the TTG; otherwise statistically significant differences between the training groups were not seen (**Table I**).

In-flight muscle strain (%MVC) decreased after the training period in both groups and most significantly in the cervical muscles, especially in the sternocleidomastoid muscles. In the trapezoid and thoracic erector spinae muscles, the effect of training was not so clearly seen. There was no statistically significant difference in

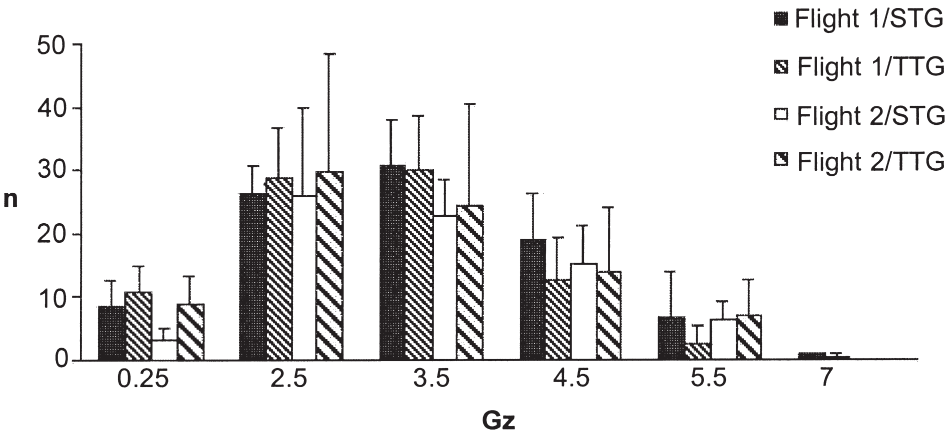


Fig. 3. $+G_z$ loading during test flights. The aircraft's G_z-meter coder recorded the number of times the given Gs were exceeded during the flight.

TABLE I. THE EFFECT OF TRAINING PERIOD ON MAXIMAL FORCES PERFORMED.

	STG			TTG			Pre- vs. Post-test	STG vs. TTG
Cervical Force	Pretest (N)	Change (%)	CI (95%)	Pretest (N)	Change (%)	CI (95%)	p	p
Flexion	316	+2.3	1.8 to 2.8	337	+3.2	2.9 to 3.5	< 0.001	0.005
Extension	155	+6.0	5.4 to 6.6	200	+6.4	5.9 to 6.9	< 0.001	0.250
Rotation	160	+6.5	−0.2 to 12.5	176	+3.1	−2.5 to 8.7	0.052	0.423

STG = strength training group; TTG = trampoline training group.

in-flight muscle strain between the training groups (**Table II**).

Results were similar in the CLT measurements. Both training methods decreased muscle strain in the cervical muscles, in both the sternocleidomastoid and in the cervical erector spinae. In the lower muscles such a clear difference was not seen. Again, between training groups there was no statistically significant difference in any measured muscle (**Table III**).

There was a tendency toward reduced EMG activity during the CLT in all muscles from the beginning to the end of the follow-up period (**Fig. 4**). The positive effects of the training period in muscle loading was sustained in the cervical area in both training groups (STG and TTG), but in the thoracic erector spinae muscles the results were not so clear. No statistically significant difference was seen between the training groups.

DISCUSSION

The results of this study indicate that training decreased muscle strain in-flight and during the CLT, especially in the lateral neck area. Both methods seemed to be efficient and their effect was still seen after a 3-mo follow-up period. The in-flight measurements were taken during ordinary flight training sorties. It is not possible to reach the accuracy of a centrifuge in $+G_z$ loading when a human is piloting an aircraft, but analysis of the $+G_z$ loading during flights evinced comparable loads between training groups as well as between the before and after training periods. Therefore, the results obtained in this study can be considered as reliable and as reflecting changes in the functional capacity of the pilots rather than in differences in external loading.

Training intervention was short, but it has been reported that with 6 wk training it is possible to increase muscle force (1,14,17), and improved muscle force has been reported to diminish in-flight strain or neck pain under $+G_z$ loading (2,6,10,18,21). The improvement in maximal muscle force in this study was small but statistically significant in both training groups, thus confirming previous findings. However, because the measurements were isometric and performed in the neutral position, the maximal forces measured probably did not show the entire increase in muscle power. Muscle force can vary greatly depending on the phase of movement (15,23,24).

Since both these training methods included rather low-intensity exercises, the increase in maximal muscle force was relatively small. It should also be considered that every training method is site- and intensity-specific, and that the accuracy of the measurements may cause small changes in the measured results. However, in this study all test subjects increased their flexion and extension forces during the training period. This supports the presumption that the changes seen in maximal forces are due to the training. In the literature, submaximal strength training or endurance training has also been reported to have a positive effect on maximal strength (3,4,12). In fact, it is likely that due to low-intensity training (both the STG and TTG), the submaximal endurance and motor coordination of the neck/shoulder area muscles were enhanced. It may be assumed that strength training would have more effect on submaximal endurance and trampoline training on motor coordination than vice versa. However, based on these results this remains a speculation. Training may cause adaptations to the many neural elements that are involved in the control of movement. Increased neuromuscular performance and intermuscular coordination may increase mechanical efficiency in maintaining cervical stability and thus have a beneficial effect in decreasing in-flight and CLT muscle strain. In this sense both training methods were successful. Even a small

TABLE II. THE EFFECT OF TRAINING ON MUSCLE STRAIN (aEMG) DURING TEST FLIGHTS DESCRIBED AS CHANGES IN %MVC.

	STG		TTG		Flight 1 vs. Flight 2	STG vs. TTG
Muscles	Δ %MVC	CI (95%)	Δ %MVC	CI (95%)	p	p
SCM	−50.3	−54.0 to −12.4	−40.8	−43.4 to 13.2	0.049	0.637
CES	−2.6	−13.1 to 5.1	−30.5	−39.4 to 18.8	0.053	0.080
TRA	−4.3	−36.2 to 3.0	−20.0	−26.0 to 8.6	0.428	0.675
TES	−7.9	25.4 to 94.2	−6.1	−38.6 to 10.0	0.933	0.637

STG = strength training group; TTG = trampoline training group.
SCM = sternocleidomastoid; CES = cervical erector spinae; TRA = trapezius; TES = thoracic erector spinae.

TABLE III. THE EFFECT OF TRAINING ON MUSCLE STRAIN (aEMG) IN THE CERVICAL LOADING TEST (CLT) DESCRIBED AS CHANGES IN %MVC.

	STG		TTG		Pretest vs. Post-test	STG vs. TTG
Muscles	Δ %MVC	CI (95%)	Δ %MVC	CI (95%)	p	p
SCM	−17.3	−21.7 to 8.7	−6.7	−29.7 to 3.1	0.059	0.291
CES	−15.7	−25.8 to −8.8	−22.0	−38.6 to 10.0	0.001	0.555
TRA	−30.0	−91.9 to −20.3	−9.5	−29.9 to 14.5	0.347	0.688
TES	−23.7	−41.8 to −1.8	−26.4	−39.0 to −11.8	0.013	0.582

STG = strength training group; TTG = trampoline training group.
SCM = sternocleidomastoid; CES = cervical erector spinae; TRA = trapezius; TES = thoracic erector spinae.

decrease in muscle strain during flight sorties may diminish muscle fatigue. Less fatigued muscles need shorter recovery times after contraction, i.e., when loaded. This also aids maintenance of muscles' safety margins during high onset rate G_z loading.

Both training methods were successful in reducing in-flight muscle strain. Training was most effective in the cervical area (sternocleidomastoid and cervical erector spinae), but a positive effect was also seen in the lower muscles (trapezius and thoracic erector spinae muscles). This may be due, in part, to the exercises. In the strength training program, both dynamic and isometric exercises were performed, mostly with cervical muscles, so the effect was naturally greatest in the muscle groups specifically practiced. Then again, there were neck flexor (back bouncing) and neck extensor specific exercises (hand and knee bouncing) in the trampoline training program, too.

In this study the muscles' in-flight %MVC levels were not very high, which differs from some other reports (8,9,16,19). This may be due to the nature of the test flights. The sorties were basic aerobatics and maneuvering with single aircraft. During air combat flights pilots need higher $+G_z$ maneuvering and move their heads to follow the other aircrafts' moves. This increases the load on the cervical muscles, especially the sternocleidomastoid muscles that also rotate, bend laterally, and resist extension of the head from the neutral position. However, both training methods had a positive effect on these critical muscles. A slight increase in strength resulted in a slight decrease of strain in the cervical erector spinae muscles. In the lower part of the spine, where the muscles stabilize the posture rather than perform movements against $+G_z$ loading, the results were more variable.

A similar change in muscle strain was seen in the CLT as during in-flight EMG-measurements. This supports the hypothesis that improved muscular capacity due to training decreases muscle strain under $+G_z$ loading. The test also excluded the effect of cadets' improved flying skills during the training period as a factor of change to muscle strain: improved flying skills or learning had no effect on loading in the CLT. The %MVC levels were higher in the CLT than during test

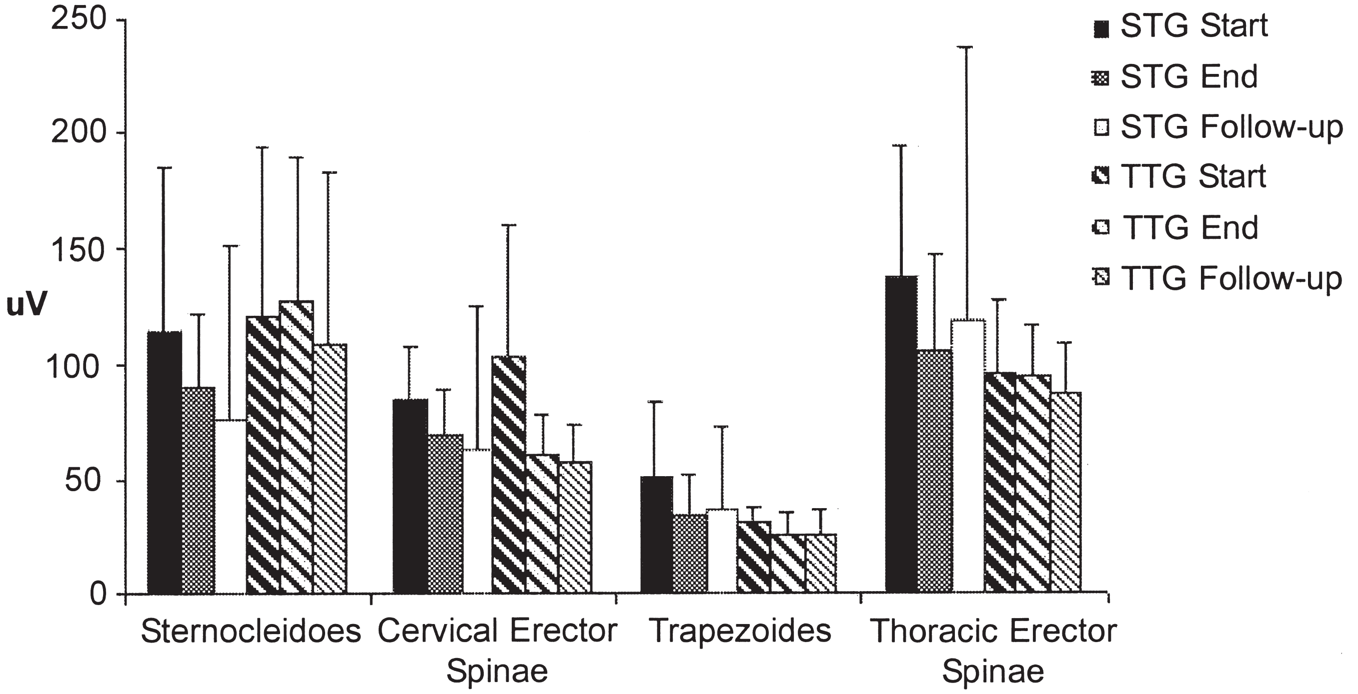


Fig. 4. EMG activity during CLT in all muscles in the beginning (pretest), on completion of the training period (post-test), and after 3 mo (follow-up).

flights, which may be due to the more impulsive and impact type loading in the CLT than the moderate, more sustained in-flight accelerations during the flights. On the other hand, in-flight recorded data also included flying between maneuvers. Even though %MVC values were higher in the CLT, these results indicate that the CLT is a sensitive method for simulation of in-flight loading over the cervical area. It is an inexpensive and simple on-site alternative to test flights and centrifuge tests, and especially useful in follow-ups.

On completion of the 3-mo follow-up period, the muscles' electrical activities during the CLT were similar to those after the training period. Decreased muscle strain in the cervical muscles was still seen, and there was no statistically significant difference between training methods. During the follow-up period, the cadets had an intensive air combat training phase with 3–4 high $+G_z$ sorties per day. Due to strenuous flying activities, the cadets recuperated after flight with little additional physical activity and no specific training program. What the training effect of flying itself was during follow-up remains to be discussed. It has been reported that the overall muscular neck strength of pilots did not differ significantly from that of non-pilots, nor did exposure to $+G_z$ forces lead to specific changes in isometric muscle strength (5,22). Still, those results may reflect the difficulty of measuring out all the specific changes in muscular tone and strength in the complex cervical column rather than the ineffectiveness of G_z loading on musculature.

In conclusion, neither of the described training methods was superior to the other, but both had positive results. Trampoline training seems to be a suitable method for diminishing in-flight muscle strain in the neck area. Exercises enhance the motor control ability of the cervical muscles, and thus pilots do not need to use as much of their muscle strength as previously. Training improves the skills related to the maintenance of situational balance, control of movement, and muscular stabilization, and this may cause a positive effect to in-flight muscle strain. In addition, strength training, even with a slight increase in maximal muscle force, has a positive effect on neck muscle strain under $+G_z$ loading. Both training methods expand the muscles' capacity in different ways. The greater the muscle capacity between maximum capacity and capacity needed during $+G_z$ loading, the smaller the risk of cervical injuries. A combined strength and trampoline training program has been included in fighter pilots' physical education programs in Finland.

ACKNOWLEDGMENTS

The study was supported by a grant from the Work Environment Fund of the Ministry of Finance.

REFERENCES

1. Abe T, DeHoyos DV, Pollock ML, et al. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. Eur J Appl Physiol 2000; 81:174–80.
2. Balldin UI, Werchan PM, French J, et al. Endurance and performance during multiple intense high +Gz exposures with effective anti-G protection. Aviat Space Environ Med 2003; 74: 303–8.
3. Bell GJ, Petersen SR, Wessel J, et al. Physiological adaptations to concurrent endurance training and low velocity resistance training. Int J Sports Med 1991; 12:384–90.
4. Braith RW, Graves JE, Leggett SH, et al. Effect of training on the relationship between maximal and submaximal strength. Med Sci Sports Exerc 1993; 25:132–8.
5. Burnett AF, Naumann FL, Burton EJ. Flight-training effect on the cervical muscle isometric strength of trainee pilots. Aviat Space Environ Med 2004; 75:611–5.
6. Coakwell MR, Bloswick DS, Moser R Jr. High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviat Space Environ Med 2004; 75:68–80.
7. Epperson WL, Burton RR, Bernauer EM. The influence of differential physical conditioning regimens on simulated aerial combat maneuvering tolerance. Aviat Space Environ Med 1982; 53:1091–7.
8. Green ND, Brown L. Head positioning and neck muscle activation during air combat. Aviat Space Environ Med 2004; 75:676–80.
9. Hämäläinen O. Flight helmet weight, +Gz forces, and neck muscle strain. Aviat Space Environ Med 1993; 64:55–7.
10. Hämäläinen O, Vanharanta H, Bloigu R. Determinants of +Gz-related neck pain: a preliminary survey. Aviat Space Environ Med 1993; 64:651–2.
11. Hämäläinen O, Visuri T, Kuronen P, et al. Cervical disk bulges in fighter pilots. Aviat Space Environ Med 1994; 65:144–6.
12. Izquierdo M, Häkkinen K, Ibanez J, et al. Effects of strength training on submaximal and maximal endurance performance capacity in middle-aged and older men. J Strength Cond Res 2003; 17:129–39.
13. Kikukawa A, Tachibana S, Yagura S. G-related musculoskeletal spine symptoms in Japan Air Self Defense Force F-15 pilots. Aviat Space Environ Med 1995; 66:269–72.
14. Knight CA, Kamen G. Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. J Electromyogr Kinesiol 2001; 11:405–12.
15. Kumar S, Narayan Y, Amell T, et al. Electromyography of superficial cervical muscles with exertion in the sagittal, coronal and oblique planes. Eur Spine J 2002; 11:27–37.
16. Le Menn M, Bigard X, Bouron F, et al. A system for recording electrophysiological signals in flight. Aviat Space Environ Med 1995; 66:443–8.
17. Macdonald RP. Physiological changes seen after six weeks sequence training. Br J Sports Med 1983; 17:76–83.
18. Newman DG. +Gz-induced neck injuries in Royal Australian Air Force fighter pilots. Aviat Space Environ Med 1997; 68:520–4.
19. Oksa J, Hämäläinen O, Rissanen S, et al. Muscle strain during aerial combat maneuvering exercise. Aviat Space Environ Med 1996; 67:1138–43.
20. Oksa J, Hämäläinen O, Rissanen S, et al. Muscle fatigue caused by repeated aerial combat maneuvering exercises. Aviat Space Environ Med 1999; 70:556–60.
21. Portero P, Bigard AX, Gamet D, et al. Effects of resistance training in humans on neck muscle performance, and electromyogram power spectrum changes. Eur J Appl Physiol 2001; 84:540–6.
22. Seng KY, Lam PM, Lee VS. Acceleration effects on neck muscle strength: pilots vs. non-pilots. Aviat Space Environ Med 2003; 74:164–8.
23. Seng KY, Lee Peter VS, Lam PM. Neck muscle strength across the sagittal and coronal planes: an isometric study. Clin Biomech (Bristol, Avon) 2002; 17:545–7.
24. Ylinen J, Nuorala S, Häkkinen K, et al. Axial neck rotation strength in neutral and prerotated postures. Clin Biomech (Bristol, Avon) 2003; 18:467–72.
25. Ylinen J, Rezasoltani A, Julin M V et al. Reproducibility of isometric strength: measurement of neck muscles. Clin Biomech (Bristol, Avon) 1999; 14:217–9.