FINAL REPORT

NIGHT VISION GOGGLES-INDUCED NECK STRAIN AND MUSCLE FATIGUE CHARACTERISTICS OF GRIFFON HELICOPTER PERSONNEL

Pain and Disability in Military Helicopter Aircrew:
The Efficacy of Exercise Training Programs in Reducing Neck Pain and Fatigue in Canadian Forces Helicopter Aircrew

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Executive Summary

The NVG-induced neck strain and muscle fatigue research project was funded by two separate sources within the Canadian Forces of the Department of National Defense:

1). Night Vision Goggles-Induced Neck Strain and Muscle Fatigue Characteristics of Griffon Helicopter Personnel (Health Services Research & Development Board and the HSR&D Secretariat, Canadian Forces Quality of Life Grant #1725981);


The purpose of the initial research project was to collect quantifiable physiological (muscle oxygenation, oxygen saturation) data, and to provide evidence-based research for the diagnosis of muscle neck strain and fatigue. This was based, in part, on the recommendations of the results obtained from the NVG-Induced Neck Strain Questionnaire Study, conducted by DRDC in August 2001, and the CF and DRDC desired deliverables. The results of this project demonstrated our success in determining that muscle oxygenation and blood volume changes can be used to monitor the physiological status of the neck musculature when exposed to NVG use. This research provided a better understanding of the biomedical issues involved in NVG-induced neck strain, illustrating that physiological differences exist between Day (non-NVG use) and Night (NVG use) missions when monitoring the trapezii muscles of the neck (see attached NVG Executive Summary, Appendix A). This research led to a number of key publications (see reference section of this report).

Based on the successful results of Project 1, Project 2 involved a 3-phase approach to study the implementation and practical outcome of an exercise training program specifically designed for CF helicopter aircrew personnel. Our results are the first to confirm the beneficial effects of different exercise training programs under controlled conditions (see attached paper submitted for scholarly publication).

The current document is the final report and completes our research funding with DND. This report provides a review of the literature on exercise training programs related to military operations, and the submission of our research paper that supports the need for implementation of exercise training programs for CF helicopter aircrew personnel.
Review of Literature Summary

Neck pain is a growing aeromedical concern for military forces on an international scale. Neck pain prevalence in the global military helicopter community has been reported in the range of 56.6% to 84.5% (Adam 2004; Ang & Harms-Ringdahl 2006; Ang et al., 2005; Aydog et al., 2004; Wickes & Greeves 2005). Despite this high prevalence, historically research examining helicopter aircrews has focused predominantly on low back pain. Currently a number of studies have emerged that have examined the flight related factors that are hypothesized to contribute to the development of flight related neck pain (Alricsson et al., 2004; Ang & Harms-Ringdahl 2006; Ang et al., 2005; Aydog et al., 2004; de Oliveira & Nadal 2004; de Oliveira & Nadal 2005; de Oliveira et al., 2001; Hamalainen et al., 1993; Harms-Ringdahl et al., 1986; Harms-Ringdahl et al., 1991; Harrison et al., 2009; Harrison et al., (in press); Harrison et al., (in press); Harrison et al., 2007; Lopez-Lopez et al., 2001; Sovelius et al., 2007; Sovelius et al., 2008; Sovelius et al., 2008; Thomae et al., 1998; Thuresson 2005; Thuresson et al., 2003; Thuresson et al., 2005; Thuresson et al., 2005; Wickes & Greeves 2005; Wickes & Greeves (in press)).

Loading factors such as the posture adopted during flight (Alricsson et al., 2001; Bowden 1987; Burnett et al., 2004; Forde et al., (in press); Pelham et al., 2005; Thuresson 2005; Thuresson et al., 2003; Weirstra 2001; Wickes & Greeves 2005), use of night vision goggles (Green & Brown 2004; Harrison et al., 2009; Harrison et al., 2007; Sovelius et al., 2008; Sovelius et al., 2008; Thuresson 2005; Thuresson et al., 2005) and vibration (de Oliveira & Nadal 2004; de Oliveira & Nadal 2005; de Oliveira et al., 2001; Harrison et al., 2009; Wikstrom et al., 1994; Wilder et al., 1982) have all been found to contribute to neck musculature fatigue. Prolonged or repeated exposure to these loading factors has been hypothesized to perpetuate or contribute to the development of neck pain (Panjabi et al., 1998; Pelham et al., 2005). Despite the high number of helicopter aircrew personnel that suffer from neck pain very few individuals seek treatment for the disorder (Adam 2004; Wickes & Greeves 2005). The focus of medical personnel should therefore be directed towards a solution that addresses not only the issue of muscular fatigue, but...
the hesitancy to seek treatment. Previous research in military and civilian populations have used exercise therapy as a treatment modality for neck pain and have found improved endurance capacity in the neck musculature and reduced self-reported neck pain (Alricsson et al., 2004; Burnett et al., 2004; Burnett et al., 2005; Conley et al., 1997; Conley et al., 1997; Falla 2004; Hamalainen et al., 1998; Netto et al., 2007; Sovelius et al., 2006; Ylinen et al., 2004; Ylinen et al., 2003; Ylinen et al., 2006).

**Keywords:** cervical pain and dysfunction, pilots and flight engineers, exercise training programs, musculoskeletal, night vision goggles
1.0 Introduction

Flight related neck pain is problematic causing personal suffering, reducing operational capabilities, and incurring high financial cost due to loss of manpower and litigation within air defence forces worldwide (Alricsson et al., 2004; Ang et al., 2005; Hamalainen et al., 1999). In helicopter aircrew, research examining dysfunction of the spine from the 1960’s to the present has focused on lower back pain and its relation to the occupational hazards of flying a helicopter (de Oliveira & Nadal 2004; de Oliveira et al., 2001; Kitazaki & Griffin 1998; Panjabi et al., 1998). Only recently, due to the increasing use of helmet mounted devices such as night vision goggles (NVG), has the issue of neck pain in helicopter aircrew become an aeromedical concern with the potential for major health implications (Ang & Harms-Ringdahl 2006; Ang et al., 2005; Harrison et al., 2007; Thuresson 2005; Thuresson et al., 2005; Weirstra 2001). The literature documenting flight related neck pain encompasses a wide range of symptoms, from relatively minor discomfort that is treated with rest and non-steroidal anti-inflammatory medication, to more serious and debilitating disorders associated with permanent removal from flying (Adam 2004; Ang & Harms-Ringdahl 2006; Butler 1992; Watson & Trott 1993). The purpose of this contemporary review is to evaluate the role occupational factors play in the development of chronic neck pain in Canadian Forces (CF) helicopter aircrew and whether exercise training targeted at the cervical spine could potentially reduce or mitigate the occurrence of this disorder.

1.01 Neck Pain and its Prevalence

Non-specific neck pain has been defined as pain perceived to be originating in the region bounded superiorly by the superior nuchal line and inferiorly by an invisible transverse line traveling through the spinous process of the first thoracic vertebra (Bogduk 2003). In most instances, the origin and precise pathophysiological mechanism(s) of chronic neck pain remains obscure. Most research is indicative of multifactorial origins, including external psychosocial and physical loading factors, as well as the psychological and biological characteristics of the
particular individual (Bogduk 2003; Bronfort et al., 2001; Netto et al., 2007; Oksa et al., 1996; Winters & Peles 1990; Ylinen et al., 2006). Some plausible causative factors have been identified, such as muscle degeneration and/or impaired neuromuscular function resulting from chronic overuse, which is frequently accompanied by symptoms of pain, muscular weakness and fatigue (Conley et al., 1997). Degenerative changes in the cervical vertebrae and disks, and nerve impingement as well as ligamentous injury (Panjabi 1998) may also lead to the expression of acute and chronic neck pain (Winters & Peles 1990).

The prevalence of neck pain in society has been previously reported to be about 67% (Côté et al., 1998). Previous research conducted using CF CH-146 Griffon aircrew found that 81% had reported experiencing neck pain. This percentage further increases to 90% for those with an excess of over 150 hours of NVG experience (Adam 2004). This inflated value occurs despite the higher level of physical fitness exhibited by a sample of ($n = 40$) CH-146 helicopter aircrew who reported predicted VO$_2$max scores of $40.9 \pm 5.1$ mL$\cdot$kg$^{-1}$$\cdot$min$^{-1}$ (Harrison et al., (in press)). The mean recorded VO$_2$max score for this sample falls within the normative standard range of 40-42 mL$\cdot$kg$^{-1}$$\cdot$min$^{-1}$ which defines this population’s fitness level as Good (The Physical Fitness Specialist Certification Manual, The Cooper Institute for Aerobic Research, Dallas TX, revised 1997).

1.02 Canadian Forces CH 146 Griffon Helicopter Pilots and Flight Engineers

A NVG-induced neck strain questionnaire administered to 138 CH-146 Griffon pilots and found 81.2% reported flight related neck pain. Of those who reported neck pain during flight, nearly 40% had experienced more than 10 episodes, indicating that pain was chronic (Adam 2004). Of those reporting neck pains during flight, over 15% felt that their worst episode was severe enough during flight to be incapacitating. This was defined as “pain that rendered the respondent unable to perform normal duties” (Adam 2004).
Within the CH-146 Griffon flight engineers, 84.5% reported neck pain related to flying. At least 50% reported experiencing more than 10 episodes. The most disturbing figure was that almost 100% reported neck pain after flight. Neck pain experienced by flight engineers after flight was severe enough to be considered incapacitating in 25% of cases, which is slightly higher than their pilot counterparts (Adam 2004).

Similar findings have been shown in other global air forces. For example, Occupational prevalence of flight related neck pain in helicopter pilots in the British Royal Air Force has been reported to be 56.6%, and air loadmaster reported a prevalence of 71.2% (Weirstra 2001). The 3-month prevalence of neck pain in Swedish military helicopter pilots was 57%, including 32% that reported frequent neck pain (Ang et al., 2005). Collectively, these results suggest that the impact neck pain has on helicopter aircrew is large enough to be having a major impact on their occupational performance and quality of life.

1.03 Critical Load of the Cervical Spine

The cervical region of the human spine has evolved to perform three basic functions: to carry large loads, allow the head to move in multiple directions, and protect the nerves located within the spinal canal while performing the previous two functions (Panjabi et al., 1998). To accomplish these tasks, the cervical spine must be mechanically stable in not only static but also dynamic movements. This stability is comprised “of the inherent passive stability of spinal column and the highly developed active stability provided by the surrounding muscles” (Panjabi et al., 1998). The following is an example which clarifies the roles of the osteoligamentous system and cervical musculature in providing stability to the cervical spine. The head of an adult is approximately equivalent to 7% of their body mass (Panjabi et al., 1998). Previous work with CH-146 aircrew reported a mean mass of 82.7 kg which is equivalent to 811 N (Harrison et al., in press)). Given the mass of the head is approximately 7% of the total body mass, the cervical spine would be required to support a load of 56.8 N. In addition to the mass of the head, a
helicopter pilot is also required to wear a helmet and NVG leading to a combined load of 36.1 N (Watson & Trott 1993). In a low visibility situation where NVG’s are required, the helicopter pilot’s cervical spine must support a total load of 92.9N. In an in vitro experimental study looking specifically at the osteoligamentous system, determined the critical load of an adult human cervical spine, to be 10.5N; any increase in mass beyond this load and the lordotic curve of cervical spine would collapse (Panjabi et al., 1998). Given the above example, the cervical musculature of an 82.7 kg helicopter pilot would be responsible for supporting approximately 82.4 N or 88.7% of the load placed on the neck (Panjabi et al., 1998). This highlights the importance of the cervical musculature in maintaining the stability of the cervical spine in these aircrew members, and the potential problems that could result if weakness or pain compromises the ability of the muscular system to develop contraction.

1.04 Cervical Musculoskeletal System.

The vertebral column is composed of four curvatures which generates an “S” or sinusoid shape. The cervical and lumbar curvatures are posteriorly concave while the thoracic and sacral curvatures are posteriorly convexed. These curvatures function to increase the resilience and flexibility of the spine, allowing it to act as a spring rather than a rigid rod (Maikala & Bhamhansi 2004). Any deviations in the sinusoidal curvature resulting from improper posture as seen during head forward flexion, places additional strain upon the spine (Panjabi et al., 1998).

The musculoskeletal system of the cervical spine is one of the most complex and dynamic systems in the human body. The cervical muscles are required to possess marked morphological diversity to enable and permit a wide variety of head movements. The ligaments’ role in stabilization is provided mainly at the end of the range of motion (Harms-Ringdahl et al., 1986) while the muscles function to supply dynamic support to movements within the neutral and slightly deviated postures (Falla 2004). Based on their moment-generating capacity, the muscles of the cervical spine can be classified as either segmental stabilizers or prime movers. The
musculature surrounding the cervical vertebrae is classified as segmental stabilizers, their role is to provide the postural support for cervical lordosis (Wilder et al., 1982). Current research has indentified pronounced weakness in these deep segmental muscles of patients with chronic neck pain, in particular the deep cervical flexors (Falla et al., 2004). The superficial and intermediate layers of the cervical muscles are known as prime movers, their primary role is movement of the head and cervical spine (Kennedy 1998). It is hypothesized that microtrauma occurs after prolonged and repeated exposure of the spine to these mechanical stressors. This accumulation of microtrauma over time may eventually lead to the development of macrotrauma, which can lead to the occurrence of dysfunction and pain (Panjabi et al., 1998).

1.05 Differential Mechanisms for Development of Neck Pain in Aircrew.

Neck pain is a significant aeromedical problem that has the capacity to interfere with a pilot’s flying abilities, concentration, safety, overall health status and leisure time activity (Alricsson et al., 2004; Ang et al., 2005; Hamalainen 1999; Wickes & Greeves 2005). There are two distinct sub-groups of neck pain related to flight: acute and chronic neck pain. Acute neck pain occurs during or shortly after a flight in response to isolated events such as a high gravitational (+Gz) turn with an unsupported neck postures. This is most commonly the case in fast jet or fixed wing aircrew as compared to helicopter aircrew (Wickes & Greeves 2005). Chronic neck pain seen more commonly in helicopter aircrew is defined as occurring over prolonged periods and is associated with a loss of function or in some cases premature degenerative changes in the cervical spine (Ang & Harms-Ringdahl 2006; Green & Brown 2004; Wickes & Greeves 2005). Below, the differences between the occurrences of neck pain in helicopter aircrew versus fast jet counterparts are further discussed.

1.051 Development of Neck Pain in Fighter Pilots. There exists a large body of literature examining the role of neck pain in fighter pilots (Alricsson et al., 2004; Burnett et al., 2004; Green & Brown 2004; Hamalainen 1999; Hamalainen et al., 1998; Hamalainen et al.,
1999; Jones et al., 2000; Moncada & Erusalimsky 2002; Sovelius et al., 2006). This research responds to the frequent reports of discomfort in the cervical region resulting from deviated head postures, unpreparedness for high +Gz manoeuvres, and/or repeated exposure to large +Gz (over +4Gz) forces (Burnett et al., 2004; Hamalainen et al., 1993). For fast jet pilots in the United Kingdom, there has been a failure to identify predictive factors relating to the development of flight related neck pain (Weirstra 2001). In contrast, Butler (Butler 2000) used fighter pilots from the USA military air force and found that neck pain correlated positively with the pilots age, flight hours, +Gz level and onset rate, duration of exposure, muscle strength, number of repeated exposures, and duration of rest between exposures. Further research examining the radiographs of 732 male flight personnel from Turkish Aerospace Medical Program found height and age had the greatest influence on prevalence of cervical radiological changes in fighter pilots (Aydog et al., 2004). However, additional research is needed to clarify the mechanisms associated with neck pain and disability in fast jet pilots.

1.052 Development of Neck Pain in Helicopter Pilots. In contrast to acute neck pain development seen in fighter pilots, neck pain in rotary winged aircrew is typically defined as more chronic. The chronic nature of the neck pain experienced by helicopter aircrew has been related to suboptimal postures adopted during flight, use of NVG, vibration, and maintenance of low level contractions for extended periods (Adam 2004; Ang et al., 2005; Forde et al., (in press); Harrison et al., 2007; Thuresson et al., 2003; Wickes & Greeves (in press)). While in flight, helicopter pilots experience smaller +Gz forces but are exposed to lower and larger vibration frequencies and magnitudes compared to fighter pilots (18). These vibrations frequencies are among the highest of all occupations, and have been linked to the premature onset of some spinal abnormalities (Butler 2000). Research using radiographs of 732 Turkish flight personnel identified an increased number of cervical spondylarthritic/spondylitic changes in helicopter pilots when compared to jet and transport pilots (Aydog et al., 2004). To determine the existence of predictive factors relating to neck pain in CF rotary winged aircrew, research
was conducted examining fitness, fight history, and cervical isometric strength and endurance of CH-146 Griffon helicopter pilots and flight engineers. The data were analyzed using logistic regression to derive a predictive equation. Preliminary data (n=40) suggests that height and longest single NVG mission recorded in the respondent’s logbook were the only variables that predicted which individuals would suffer from neck pain (Harrison et al., (in press)). However, more research is needed to clarify this finding with a larger population of both fast jet and helicopter aircrew. Furthermore, Harrison et al. (Harrison et al., (in press)) could not isolate differences between helicopter pilots and flight engineers despite the discrepancies in their occupational duties. Given the common link between the development of flight related neck pain in both CH-146 pilots and flight engineers, a cervical training program that addresses this common issue has the potential to beneficial for both. A questionnaire administered to Swedish military helicopter pilots found history of previous neck pain and recent shoulder pain were the only significant predictors for neck pain. Although not significant, NVG utilization and/or experience contributed to the overall risk of neck pain (Ang & Harms-Ringdahl 2006). Wickes & Greeves (Wickes & Greeves (in press)) also examined survey data from the British RAF and found that total number of NVG flying hours was associated with increased probability of having suffered flight related neck in helicopter pilots.

1.06 Hypothesized Development of Neck Pain

Currently there is no encompassing hypothesis to explain the onset of neck pain. Research indicates that the origins of neck pain are likely multifactoral (Falla 2004; Sarig-Bahat 2003; Visser & van Dieen 2006; Ylinen et al., 2006). For the purpose of this review we will focus on two hypotheses that the author feels are most relevant to the population of interest and the onset of fatigue and damage due to contraction of the cervical musculature.

1.06.1 Cinderella Hypothesis. The Cinderella Hypothesis provides a plausible explanation for damage that is seem in the muscle fibres in response to low intensity loading
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(Visser & van Dieen 2006). The premise of this hypothesis is grounded in the size principle, which states that small, low-threshold muscle fibres are continuously activated during submaximal tasks. They have illustrated that muscle fibres in a muscle are recruited in a stereotypical manner. Initially small Type I fibres are recruited for low intensity contractions, before recruitment of larger more powerful Type II fibres. These Type I fibres will remain activated until force requirements increase or the muscle relaxes (Henneman et al., 1965). In flight electromyography (EMG) analysis has documented contraction levels of below 15% of the maximal voluntary contraction (MVC) force in the cervical musculature (Netto et al., 2007). Depending on the flight schedule of the aircrew pervious work has reported total flight experience in the range of 1318.5 hrs ± 1128.5 (Harrison et al., (in press)). Given these findings the repeated and continuous low intensity loading of Type I muscle fibres is very much a reality for helicopter aircrew. The Cinderella Hypothesis proposes that the continuous activation of the small Type I motor-units during low-intensity sustained tasks is the precursor for future damage to these motor-units (Henneman et al., 1965). Hagg et al., (Hagg 2000) conducted a review of ten biopsy studies whose sample populations were predominantly female with myalgic complaints as a result of static or highly repetitive work. The results indicated those with myalgic complaints when compared to pain free controls demonstrated decreased capillary density per fibre cross-sectional area. There was increased association between the number of “ragged red fibres” (i.e., fibres lacking the active enzyme Cytochrome oxidase) and the severity of the myalgic complaint (Hagg 2000). Although the Cinderella hypothesis is a plausible explanation for selective loading of Type I fibres, it does not explain the mechanism(s) of muscle fibre damage (Visser & van Dieen 2006).

1.062 Nitric Oxide/Oxygen (NO/O₂) ratio hypothesis. Another potential explanation for the occurrence of neck pain in helicopter aircrew is the NO/O₂ ratio hypothesis. The occurrence of low-intensity muscle contractions increases the intracellular concentration of Ca^{2+} released
from the sarcoplasmic reticulum. The release of Ca\(^{2+}\) stimulates the production of nitric oxide (NO) from amino acid L-arginine by a family of enzymes termed nitric oxide synthase (NOS) in the muscle cell (Alderton et al., 2001). NO is a highly diffusible, gaseous messenger molecule that plays a vital role in many biological functions but mainly in local vasoregulation (NO is a powerful vasodilator), neurotransmission, and immunological responses (Moncada & Erusalimsky 2002). Reduced capillary blood flow due to sympathetic vasoconstriction inhibits destruction of NO by molecules such as myoglobin (Beckman & Koppenol 1996). A fall in intracellular oxygen concentration coincides with decreased blood flow. These events combine to contribute to the rise in the ratio of NO/O\(_2\) in the muscle cells, facilitating the reversible and competitive inhibition of cytochrome oxidase (CytOx), the terminal enzyme in the mitochondrial electron transport chain, by NO (Moncada & Erusalimsky 2002).

When CytOx is inhibited, its capacity to generate adenosine triphosphate (ATP) aerobically is reduced. At the same time, the muscle continues to perform low intensity contractions which further deplete ATP stores. With a drop in the availability of ATP coupled with the inhibition of CytOx, the muscle relies on anaerobic glycolysis to generate ATP, which results in the production of lactic acid (Juel 2001; Spriet et al., 2000). The efflux of lactic acid from the cell activates proton-sensitive nociceptive fibres, resulting in myalgic pain (Immke & McCleskey 2001; Issberner et al., 1996; Sutherland et al., 2000). With sustained inhibition of CytOx by NO for a periods lasting hours, peroxynitrile may be generated. Peroxynitrile is capable of irreversible inactivation of some enzymes in the electron transport chain. If this is repeated over an extended period such as months or years, the production of “ragged red fibres” also known as moth-eaten fibres that lack the enzymatic capacity for cellular aerobic respiration can result (Brown & Borutaite 2002; Moncada & Erusalimsky 2002; Radi et al., 2002).
1.07 Neuromuscular and Metabolic Parameters of Flight

To explain the development of flight related neck pain in helicopter aircrew an understanding of the neuromuscular and metabolic stresses placed on the cervical musculature during flight is essential. However, to the best of our knowledge there is little research that has examined these stressors during helicopter flight. Current research is limited to laboratory environments or data from a flight simulator (Forde et al., (in press); Harrison et al., 2009; Harrison et al., (in press); Harrison et al., (in press); Harrison et al., 2007; Thuresson 2005; Thuresson et al., 2003; Thuresson et al., 2005). In an attempt to quantify a dose-response relationship between head borne load and neuromuscular activity of the neck, Jonsson (Jonsson 1982) calculated a muscular strength utilization ratio (MUR). MUR is the ratio between the load moment produced by the mass of the neck, head, helmet, equipment worn on the helmet and the maximum cervical strength multiplied by 100. If the a load was to be maintained for a period longer than an hour an upper limit of 5% of the MUR was recommended. In a laboratory environment examining the EMG activity of upper and lower neck musculature induced by different head worn equipment and neck postures, Thuresson et al. (Thuresson 2005) found in a neutral posture that % MUR exceeded the 5% recommendations with any head born equipment, with the exception of the helmet only condition. In a cervical flexed position wearing a helmet and NVG, a MUR of 16% was recorded. In-flight EMG analysis at +1Gz in fighter pilots identified upper limit cervical activity levels of approximately 15% of the maximal isometric force (Netto et al., 2007). Although occupational conditions vary between the two modes of flight, helicopter aircrew would experience gravitational forces of approximately +1-2Gz and it would seem reasonable to estimate that the upper limit cervical activity threshold levels may be comparable in that population.

Research on lumbar neuromuscular activity in the right and left erector spinae of helicopter pilots during flight found that 88% of the subjects experienced contraction levels below 5% of maximal voluntary contraction (MVC). During an average 2 hr flight, the erector
spinae of the entire sample population operated at a level well below the threshold of 14% MVC (de Oliveira & Nadal 2004). Based on these findings, it can be concluded that during a flight, helicopter aircrew cervical spines’ are contracting at low submaximal levels. Previous research investigating flying hours of CH-146 helicopter aircrew in the Griffon helicopter reported mean total flying hours ranging from 1159.7 ± 945.7(44) to 1203 ± 888 (Adam 2004). Also reported was total hours of NVG use which ranged from 136.1 ± 120.4 hrs (44) to 172 ± 137 hrs (Adam 2004). Harrison et al. (Harrison et al., (in press)) also reported the longest NVG flight to be 3.1 ± (1.8) hrs. Given these facts we know that helicopter aircrew cervical spines are contracting at low submaximal threshold that would likely not exceed 15% MVC, combined with these flight histories, indicated repeated exposure for prolonged period of time. Using the previously discussed Cinderella Hypothesis and NO/O2 Ratio Hypothesis we can predict that the small Type I muscle fibres in the cervical musculature of helicopter aircrew are being repeatedly stimulated throughout the course of a flight to maintain low level isometric contractions. The maintenance of these low level contractions could potentially lead to development of ragged red fibres leading to the experience of pain and fatigue in the cervical spine (Visser & van Dieen 2006).

1.08 Factors Contributing to Flight Related Neck Pain in Helicopter Aircrew

Recent technological advances in airframes, composite materials, propulsion systems, flight controls and avionics allow helicopters and jets to travel faster, longer and higher (Seng et al., 2003). Innovations have also extended to other technologies such as flight helmets, head display units (HDU) and NVG, which are critical for operational success (Adam 2004). The flight helmet was designed initially as protective equipment but as technology improves its role has evolved to include a mounting platform for devices such as HDU and NVG (Sovelius et al., 2006).

1.081 Night vision goggle usage. Equipment affixed to the helmet is becoming more prevalent in helicopter pilots and flight engineers to allow flights in low visibility conditions (i.e.
during cloudy conditions or under the cover of darkness) (Adam 2004). NVG use near-infrared light to enhance ambient light reflected off objects within the field of view (refer to Figures I & II). One drawback to NVG use is a reduction in the user’s peripheral vision - the AN/AVS-9 model used by Canadian CH-146 Griffon aircrew has a 40° field of view (Task & Filipovich 1997). Forde et al. (Forde et al., (in press)) measured postures adopted while wearing NVG during a simulated night flights. Subjects were found to spend increased time in mild (74%, defined as 10-30° of cervical flexion) and severe (10%, greater than 35° of cervical flexion postural positions when compared to day flights without NVG. Increased time spent in mild axial twist postures was also identified in CH-146 Griffon helicopter pilots when comparing simulated day (35%) to night (63%) flights. These findings indicate that pilots spend a higher percentage of their work cycle in high risk postures (severe cervical flexion and axial twist postures) resulting in higher peak and cumulative loads placed upon the cervical spine, especially during night flights (Forde et al., (in press)).

Use of head worn equipment increases the mechanical load placed on the cervical vertebrae and the skeletal musculature supporting the neck. Increased load alters the center of the gravity head forward and upward with respect to the motion axis of the cervical spine (Harms-Ringdahl et al., 1999). This additional flexion moment on the neck increases the work required from the posterior cervical extensors to control movement and head posture (Sovelius et al., 2008). The addition of mass to the helmet for individuals in a seated static posture in an F-15 ACES II ejection seat revealed increased muscle fatigue in the cervical spine when the helmet configuration was combined with added weight and a forward shift in the center of gravity (Gallagher et al., 2007). Any equipment mounted on the helmet, except on the normal center of mass for the head, places additional loads on the muscles and the cervical vertebrae (Forde et al., (in press)). The impact of impulsive (0-4) +Gz forces on a neutral spine simulated using a trampoline, increased muscle strain in sternocleidomastoid, trapezius and the cervical erector spinae in response to the helmet mass alone. The addition of NVG to the helmet significantly
increased muscle strain in the sternocleidomastoid, and cervical erector spinae muscles (Sovelius et al., 2008).

Using myoelectric manifestations (EMG) as an index of fatigue Sovelius et al. (Sovelius et al., 2008) found that NVG induced an increase in cervical muscle strain that was greatest for the muscles that were already specifically loaded. In an impulsive (0-4 +Gz) gravitational environment the authors found that the increased frontal load induced by NVG was not evenly distributed across the cervical musculature. Rather it appeared to affect those muscles that were already subjected to the highest loading, as seen in the sternocleoidmastoid during back bouncing and the cervical extensors during hand and knee bouncing on the trampoline (Sovelius et al., 2008).

Harrison et al. (Harrison et al., 2007) assessed the metabolic stress placed on the cervical spine as a result of NVG use with near infrared spectroscopy (NIRS). An increased blood volume and oxygenation response was recorded in the trapezius when NVG simulated flight was compared to a helmet only condition. The use of NVG induced sufficient metabolic stress in the upper trapezius muscles, bilaterally, that increased blood volume was required to meet the oxygen demands of the contracting muscles. This would indicate that NVG use during night flights places increased metabolic demands on the trapezius muscle (Harrison et al., 2007).

1.082 Posture. Research has established that helmet mass increases muscle strain (Sovelius et al., 2008) and metabolic responses (Harrison et al., 2009; Harrison et al., 2007) experienced by cervical musculature; however, the role posture and head movements play in muscle strain development maybe even more significant. Laboratory based EMG analysis revealed that neck and body position had a substantially greater effect on neck muscular activity than the mechanical load of head worn equipment (Thuresson et al., 2003; Thuresson et al., 2005). The ergonomic design of the helicopter cockpit, forces pilots to adopt a forward flexed position of the trunk and cervical spine (refer to Figures III & IV). The major portion of this

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forward flexion occurs in the lumbar and thoracic spine and has been cited as a plausible mechanism for the onset of low back pain (Pelham et al., 2005). Lopez-Lopez et al. (Lopez-Lopez et al., 2001) described the posture adopted by helicopter pilots as being slightly forward and rotated to the left due to the location of crucial flight controls (i.e. the collective and the cyclic). Adoption of this kyphotic lumbar and thoracic posture (convexly curved) forces the lower cervical spine into flexion and the upper cervical spine into extension. In this position, the upper cervical spine musculature is continuously activated, which over extended periods can be fatiguing (Adam 2004). This constant state of muscular contraction could potentially lead to damage and anterior compression of the intervertebral discs, which with repeated exposures would contribute to the development of neck pain (Pelham et al., 2005).

RestRAINT of the torso and shoulders by the 4-point safety harness, standard issue for helicopter pilots, also functions to restrict movement of the thoracic and lumbar regions of the spine. This restriction forces a greater proportion of required movement be accommodated for by the upper thoracic and cervical vertebrae. This accommodation places considerable stress on the neck during excessive movements such as the check 6 position (i.e. rotation of the cervical vertebrae in looking towards the rear of the aircraft) and is exacerbated by the addition of NVG and other head mounted equipment (Wickes & Greeves 2005). The results of posture matching based on video records of CH-146 helicopter pilots during simulated night and day flights concluded that “pilots may be at an increased risk of developing neck strain during NVG flights since the majority of their time is spent in flexed postures greater than 15 degrees” (Forde et al., (in press)).

To identify specific stresses placed on the spine due to cockpit design, research using EMG (neuromuscular component) and NIRS (metabolic component) has been conducted to quantify the loads placed on the bilateral musculature. Investigation of static posture with trunk rotation of 15°, 30°, and 45°, combined with the development of torque equivalent to 20%, 40%, 60% and 100% of MVC, found more activity contralateral to the side of rotation starting at 20%
of MVC (Dieen 1996). Based on this study one would expect to see higher levels of contraction of the right side of the spine. Lopez-Lopez et al. (Lopez-Lopez et al., 2001) used surface EMG to measure the back muscle activity of helicopter pilots during flight to support this hypothesis. They found a higher prevalence of muscular activity on the right side, concluding that the posture adopted during flight imposed a higher metabolic demand on the right than the left side. In contrast de Oliveira et al. (de Oliveira et al., 2001), found higher albeit not significant EMG activity on the left rather than the right during a short flight. Data from longer flights (approximately 2 hrs) found no differences between EMG signals between the left and right sides (de Oliveira & Nadal 2004).

Harrison et al. (Harrison et al., 2007) found differences between the left and right trapezius for total haemoglobin (tHb), oxygenated haemoglobin (HbO₂), and deoxygenated haemoglobin (HHb) in 33 helicopter pilots using NIRS during flight simulation (CH-146 Griffon helicopter simulator). Higher values of tHb and HbO₂ were found on the right side suggesting an increased response to meet the increased metabolic demands occurring in the right cervical musculature. This further supports the idea of a higher level of contraction on the right relative to the left side as reported by Lopez-Lopez et al (Lopez-Lopez et al., 2001).

1.083 Whole body vibration. Whole-body vibration (WBV) is vibration transmitted to the entire body from a vibrating surface such as a seat in a vehicle such as a truck, bus or aircraft (Maikala & Bhambhani 2004). While in the seated position “human exposure to vertical whole-body vibration has consistently shown the principal resonance frequency of the upper body to be in the vicinity of 5 Hz” (de Oliveira & Nadal 2005). Chen et al. (Chen et al., 2007) measured the vibration spectrum of the Bell 412 helicopter (civilian model of the Canadian CH-146 Griffon). They found that the principal harmonic frequency was approximately 5Hz. During whole body vibration, maximum energy transfer to the human spine occurs within the range of 4.5-5Hz (Maikala & Bhambhani 2004). Given the vibration frequency of the Bell 412 individuals flying
these aircrafts was likely experiencing maximum energy transfer in their spine. Chen et al. (Chen et al., 2007) evaluated the displacement of the helmeted head of a Bell 412 pilot who was exposed to the 5Hz vibration frequency. They found that the pilot’s head underwent Z-axis displacements twice the magnitude of the Z-axis displacement occurring on the floor of the aircraft. It has also been demonstrated that vibration transmission from the buttocks to the head in a seated posture increased in an exponential manner (Wilder et al., 1982). Therefore, the vibration frequency experienced by the neck is higher than that experienced by the lower back. Also of primary significance during whole body vibrations is the posture assumed by pilots, described as flexed and rotated to the left; this awkward body position combined with seated vibrations poses the greatest risk for the development of back problems (Kitazaki & Griffin 1998).

Bonger et al. (Bongers et al., 1990) found that vibration was a significant cause of low back pain in British pilots. The long duration and low amplitude vibrations of helicopters has been found to increase the incidence of cervical spondylarthritic changes in Turkish pilots (Aydog et al., 2004). Development of localized fatigue due to a variety of postures and vibration frequencies was consistent with EMG data that assessed the effect of WBV on the paraspinal muscles in the low back (Hansson et al., 1991; Pope et al., 1990; Wilder et al., 1982). Research has shown that WBV induced a localized vasoconstriction stimulus in the lumbar regions of the erector spinae muscles (Maikala & Bhambhani 2004). A reduction in blood flow resulted in lowered blood volume based on the greater deoxygenation signal obtained by NIRS. In contrast, Pope et al. (Pope et al., 1986) found that posture, not vibration, played the most significant role in the development of back muscle fatigue. This hypothesis was supported by research that also failed to isolate a change in muscle activity due to vibration (de Oliveira & Nadal 2004). However, more data in both of these areas are needed to elucidate the contribution of vibration and posture.
1.09 Use of Exercise Therapy in Pilot Populations

A survey assessing neck pain in Canadian CH-146 Griffon helicopter pilots found that less than half of these pilots sought treatment for their pain (Adam 2004). Previous research conducted using British RAF found that less than 30% of all aircrews sought medical attention for neck pain (Wickes & Greeves 2005). The majority were uncomfortable with medical staff, and/or cited a fear of grounding as reasons for their hesitancy to seek medical attention. The prevalence of neck pain in this aircrew provides incentive for developing a suitable treatment option that would be used by the aircrew. Conservative interventions such as physiotherapy, manual therapy, massage, exercise therapy, and ergonomic interventions have been the focus of research involving female office workers. Despite the use of these therapies, systematic reviews and meta-analyses of the literature in regard to the effectiveness of these types of treatments indicate that most studies contain design flaws and the beneficial effects of these interventions have yet to be rigorously supported (Kay et al., 2005; Sarig-Bahat 2003; Smidt et al., 2005).

Exercise therapy is cited as the most commonly used treatment modalities for non-specific neck disorders. Exercise therapy is defined as “therapy [that] involves the prescription of muscular contraction and bodily movement ultimately to improve the overall function of the individual and help meet the demands of daily living” (Smidt et al., 2005). For the occupational environments associated with flight, research examining the role of exercise therapy in the alleviation of neck pain has focused mainly on fast jet pilots (Alricsson et al., 2004; Burnett et al., 2004; Hamalainen 1999; Hamalainen et al., 1998; Jones et al., 2000; Sovelius et al., 2006), with limited research in helicopter pilots.

1.10 Chronic Neck Pain and Presence of Strength and Weaknesses

Numerous studies have illustrated reduced cervical strength and endurance capacity in the cervical extensor and flexor muscles in individuals with neck pain (Barton & Hayes 1996; Falla 2004; Treleaven et al., 1994; Watson & Trott 1993). Falla et al. (Falla et al., 2003) assessed
the fatigue of the superficial flexors, sternocleiodmastoid and the anterior scalene muscles during sustained cervical flexion contractions at 25% and 50% of the MVC in patients with chronic neck pain. Greater myoelectric manifestations of muscle fatigue in the sternocleiodmastoid and anterior scalene muscles in individuals with neck pain relative to the controls was observed when the slope of the EMG mean frequency was assessed. Gogia and Sabbahi (Gogia & Sabbahi 1994) similarly established greater cervical flexor muscle fatigability during low load sustained contractions (25% MVC).

To examine muscle activation patterns, Falla et al., (Falla et al., 2003) developed an EMG technique capable of measuring the activation levels of the deep cervical flexors. Using suction a surface electrode was attached to the posterior oropharyngeal wall via nasopharyngeal cavity. This technique has been used to examine activation levels variances during the performance of the cranio-cervical flexion test for those reporting neck pain compared to controls (Falla et al., 2004). Neck pain patients exhibited disturbances in the neck flexor synergy “where impairment in the deep muscles, important for segmental control and support, appeared to be compensated for by increased activity in the superficial muscles” (Falla 2004).

Given that increased EMG activity has been identified in the superficial cervical musculature of individuals with neck pain (Jull 2000; Jull et al., 2004), the neuromuscular efficiency (NME) of the sternocleidomastoid and anterior scalene muscles must also be investigated. The NME was defined as the quotient of force and the integrated EMG during a cervical flexion contraction at 25% and 50% of MVC in individuals with and without neck pain (van der Hoeven et al., 1993). These authors found less NME for the sternocleidomastoid and anterior scalenes when contracting at 25% MVC in individuals with neck pain. The reduced NME illustrates that individuals with neck pain required higher levels of electrical muscular activity to produce an equivalent force relative to the controls, or conversely with a comparable level of electrical muscular activity, neck pain patients generate a lower force output (Falla 2004).
1.11 Research Relating Neck Pain and Exercise Training in the General Population

Conley et al. (Conley et al., 1997) assigned 22 pain free college students to either a control or two treatment groups (RESX and RES), each group performed a full body resistance training program. The RESX program also included head extension exercises. Post-test examination of the cervical musculature indicated that the provision of neck specific exercises in a conventional resistance training program was necessary to increase the cross sectional area of the neck musculature and improve neck extension strength. The isometric contractions of the muscles of the cervical spine required for stabilization during a conventional resistance training program was insufficient to generate neck muscle hypertrophy. These results support the conclusion that the gravitational load placed on the cervical musculature is only modest in an upright posture, thus necessitating the need for neck specific exercises to stimulate increases in cervical musculature cross sectional area (Conley et al., 1997).

In a 12-month study assessing the effects of cervical resistance training on 180 female office workers, maximal isometric neck strength found relative to the endurance and control groups, the resistance training group was the only treatment group with statistically significant increases in neck lateral flexion, flexion, and extension (Ylinen et al., 2003). A negative linear association between neck pain and disability indices with improved isometric neck strength (Ylinen et al., 2006). The large improvements in strength found in the female office workers are not likely reflective of the strength increases expected in the military aircrew. During each flight, CH-146 helicopter pilots and flight engineers submit their cervical musculature to mechanical stressors in the form of the flight helmet, or flight helmet and NVG, the 1-2 +Gz forces, and sustained periods of WBV. These mechanical stressors should result in some form of hypertrophy of the cervical musculature. It would therefore be expected that this military aircrew would have higher baseline cervical strength and endurance and should therefore see smaller gains in strength compared to studies looking a female office workers.
In contrast to the results the previously discussed results, Nikander et al. (Nikander et al., 2006) found that both strength and endurance training decreased perceived neck pain and disability equally regardless of intervention assignment. They found a 20 mm decrease in neck pain on the Visual Analog Scale for those who trained for more than 8.75 metabolic equivalent hours (MET•h⁻¹) per week, or 35 MET•h⁻¹ of training per month. The greatest dosage of the specific training had the largest effect on neck pain symptoms. However, all patients who complied with more than 35 MET•h⁻¹ per month belonged to the resistance training group; “[i]t may be more probable to complete 40 min of specific higher-load strength exercises than 60 min of endurance training with 2-kg dumbbells” (Nikander et al., 2006). Randlov et al. (Randlov et al., 1998) evaluated the neck pain associated with the activities of daily living. They found reductions in pain scores only for subjects in the higher intensity program and not in the lower intensity program after a 12 month follow-up period.

1.12 Neck Pain and Exercise Training Regimes in the Air Force

Research using self-reported risk factors (questionnaires) showed that prevalence and development of neck pain in helicopter pilots was decreased when engage in regular aerobic exercise (Wickes & Greeves 2005) and muscle strength training (Ang & Harms-Ringdahl 2006). However, limited prospective research is available in helicopter pilots to confirm that exercise can reduce neck pain and disability related to flight.

Previous research conducted using fast jet pilots should be taken into consideration for program development. At the same time, the unique flight environment in which the helicopter aircrew operate and must be considered. In a study of Swedish fighter pilots, they found no reduction in neck pain with increased strength and endurance of the neck musculature after completing a strength training program. However, the reinforced group and the non-reinforced group differed in baseline strength measurements, groups were not randomized (rather they were geographically determined), and there was no true non-treatment control group. The existence of confounding variables, such as differential history and maturation effects, provide alternative
explanations for the observed changes in the neck muscle strength and endurance seen in the reinforced and non-reinforced groups (Alricsson et al., 2004).

These findings are in contrast to the research on fast jet pilots comparing the effects of a weighted helmet training program versus a dynamic program. The study showed that pilots in the dynamic training program had fewer workdays lost and restriction in +Gz flights than the weighted helmet group. Isometric neck muscle strength increased similarly irrespective of training group status, and no differences were identified in the passive cervical range of motion. However, the study lacked both a control and had a small sample size (Hamalainen et al., 1998). Both trampoline and strength training have shown positive effects on the cervical spine through decreases in muscle strain experienced in-flight and during cervical loading tests. After a three month follow-up, the improvements in muscle strain remained for both training interventions (Sovelius et al., 2008).

Additional research using non-air force military individuals showed improvements in cervical strength as a result of resistance training program. Research employing a Multi-Cervical Unit (MCU), a pin loaded machine that is able to apply constant resistance through the full range of motion, 3 days a week for 12 weeks found improvements in isometric strength and dynamic strength occurred within 4 weeks and continued until the final assessment when compared to the control group (Taylor et al., 2006). Despite the success of the MCU, Taylor et al. (Taylor et al., 2006) acknowledged potential drawbacks including the cost of the MCU and that use was limited to one individual at a time. Burnett et al. (Burnett et al., 2005) compared the effectiveness of the MCU relative to Thera-Band (Pro-Med Products, Inc.) tubing as training methods to improve cervical muscle strength determined using MVC. The MCU produced the greatest improvements in isometric strength: 64% in flexion, 63% in extension, 53% in left lateral flexion and 24% in right lateral flexion. The strength improvements in the Thera-Band tubing group were 42% in flexion, 30% in extension, 26% in left lateral flexion and 24% in right lateral flexion. When compared to the control, the MCU group achieved improvements in all directions tested while
the Thera-Band tubing group was limited to flexion direction. However, the authors noted that a limitation of the study was the baseline and post-test assessments for all subjects were conducted using the MCU, which favoured those individuals training on the MCU. Despite the lack of statistically significant results, the authors concluded that the Thera-Band tubing was a valid training mode given its low cost and portability (Burnett et al., 2005). This conclusion was supported by Netto et al. (Netto et al., 2007) who compared elastic tubing and a resistance machine at different intensities to muscle activation during aerial combat manoeuvres. They speculated that neck resistance training using elastic tubing may be most practical for pilots who are exposed to small gravitational forces during flight and who maintain more neutral neck postures such as transport, bomber or helicopter pilots (Netto et al., 2007).

1.13 Changes in Cervical Muscles in Response to Resistance Training

The provision of an exercise program consisting of strength and endurance components has the capacity to increase the isometric strength and endurance of the flexors and extensor muscles of the cervical spine (Alricsson et al., 2004; Hamalainen et al., 1998; Sovelius et al., 2006). The ability of a muscle to generate force is related to the cross sectional area (Ikai & Fukunaga 1970; Maughan et al., 1983); which includes the cervical musculature (Mayoux-Benhamou et al., 1989). It is hypothesized that an increase in the cross sectional area of the neck musculature has the potential to provide increased stability to the cervical spine, functioning to limit or prevent musculoskeletal impairment (Conley et al., 1997). Given that 80% of cervical stabilization is provided by the cervical muscles, improving the force production from these muscles should theoretically lead to enhanced stabilization of the cervical spine.

Resistance training is a mechanical stress that stimulates various adaptations of the neuromuscular system, the most notable being increases in muscle size and strength. These adaptations are related to the characteristics of the specific exercises employed in the training program. This phenomenon is referred to as the principle of specificity which states that the
greatest improvements in force and function will be seen in activities that reflect the mode of training (Conley et al., 1997). Given the specificity of training response, and in light of the limited research on exercise training programs in helicopter pilots, an appropriate program should focus on training the Type I postural muscle groups.

2.0 Exercise Training Programs

Based on the evidence gathered from this literature review we have purposed the following exercise treatment programs: (a) general neck strength and muscle coordination training program (CTP); and a (b) neck muscle endurance training program (ETP).

2.01 Neck muscular endurance training program. Muscle fatigue is a major risk factor in the development and occurrence of muscle injuries. For aircrew, it has been suggested that fatigued muscles increase the risk of neck injury and have the potential to reduce mission effectiveness. Muscle activity of the cervical spine related to flying a helicopter is generally lower than that generated during a high +Gz flight (Ang et al., 2005). Loading factors such as posture, whole body vibration and increased head mass associated with helicopter flight are factors that also contribute to muscle fatigue (de Oliveira & Nadal 2004; de Oliveira & Nadal 2005; Harrison et al., 2007; Thuresson et al., 2003; Thuresson et al., 2005).

Endurance training focuses on increasing the ability of muscles to continue prolonged submaximal work. To maintain repeated prolonged submaximal contractions over time, there must be a transition to more fatigue resistant muscle fibres, which rely predominantly on aerobic metabolism (Powers & Howley 2004). To combat the generation of fatigue, dynamic endurance training should be incorporated into the research design. An increase in the number of fatigue resistant fibres in the cervical musculature should offset the development of neck fatigue and pain.
Previous research examining the effect of dynamic endurance training programs on fighter pilots found fewer sick leaves and +Gz restrictions compared to resistance training programs (Hamalainen et al., 1998). Ylinen et al. (Ylinen et al., 2003) identified endurance training improvements in maximal isometric neck strength during a 12 month training period to be 28% in flexion, 29% in rotation and 16% in extension. For rotary winged aircrew, the ability to sustain a low level contraction is of greater importance than generating high levels of force (Harrison et al., 2009).

2.02 General neck strength and muscle coordination training program. This program was proposed in a review on the complexity of muscle impairment in chronic neck pain conducted by Falla (Falla 2004). In contrast to the neck muscular endurance training program, this exercise regime uses low load exercises to train and re-establish coordination between the deep and superficial layers of the neck musculature. The first aspect of this program focuses on muscle control, where low load exercises are used to enhance the coordination between the layers of cervical musculature (Falla 2004). This motor control aspect “is based on biomechanical evidence of the functional interplay of the deep and superficial neck muscles and on the physiological and clinical evidence of impairments in these muscles in neck pain patients” (Falla 2004). The first stage of training focuses on specific exercises designed to isolate the deep segmental cervical stabilizers that support and maintain the neutral cervical lordosis curvature. The second stage integrates limb motion while the deep segmental stabilizers are challenged to maintain a neutral cervical spine. The third and final stage focuses on the interplay of the deep stabilizers and the superficial prime movers. The deep stabilizers are required to support the neutral lordotic curve of the cervical spine while the superficial musculature is employed for segmental control during neck motion (Kennedy 1998). The development of this program follows from the suggestions of Äng et al. (Ang et al., 2005) who reported altered myoelectric manifestations in the form of flatter EMG-slopes for helicopter pilots reporting neck pain relative
to pain free controls. It is common for helicopter pilots to maintain suboptimal static postures for extended periods of time. Äng et al. (Ang et al., 2005) indicated clinical interest in using “low-load therapeutic exercise, emphasizing neck muscle control rather than strength” to combat neck pain in this aircrew.

See **Appendix B** for the results of our final research project, submitted for publication (Abstract only).

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Review of Literature Figures
Figure I: Front view of the Canadian Forces standard issue CH-146 flight helmet with night vision goggles

Figure II: Lateral view of the Canadian Forces standard issue CH-146 flight helmet with night vision goggles
**Figure III:** Pilot seated in CH-146 helicopter while wearing night vision goggles

**Figure IV:** CH-146 pilot demonstrating posture used to check instrument panel while wearing night vision goggles
Appendix A: Project 1 - NVG Executive Summary

<table>
<thead>
<tr>
<th>Research Project Title</th>
<th>Night Vision Goggles-Induced Neck Strain and Muscle Fatigue Characteristics of Griffon Helicopter Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principle Investigator</td>
<td>Dr. J. Patrick Neary</td>
</tr>
<tr>
<td>Contact Phone Number</td>
<td>506-453-5035</td>
</tr>
<tr>
<td>Project Start Date</td>
<td>15 June 2004</td>
</tr>
<tr>
<td>Project End Date</td>
<td>31 March 2005</td>
</tr>
<tr>
<td>Funds Granted</td>
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</tr>
<tr>
<td>Total Funds Used (per FY)</td>
<td>$47,977.47* (unused portion returned to QoL)</td>
</tr>
</tbody>
</table>

* The project team had planned for a much smaller surplus but circumstances beyond our control resulted in an aborted purchase late in the FY (i.e., a PO# was requested 28 February 2005 from Quality of Life Research Grant Program but was not provided).

1) **Background:**

   a) **Brief review of history of the projects beginning:**

   It had been determined, and well documented by Canadian Forces (CF) expertise, that there existed a significant problem in the neck musculature and spinal column of flight personnel related to wearing NVG equipment during flight in both rotary and fixed wing aircraft. This was not only a safety concern (both short-term and long-term health implications) for the Instructor Pilots and Flight Engineers involved in their occupation during these operations, but this also has significant financial and fiscal implications for the Canadian Forces. This thesis comes from the following reports:


5. Research Questionnaire conducted by DRDC (*NVG-induced Neck Strain Questionnaire Study: DCIEM Ethics Protocol L-442*), Captain Jameel Adam and Mr. Bill Fraser, Reported 9 March 2004, Toronto.


In particular, the DRDC questionnaire (and DRDC Brainstorming Session, 9 March 2004) clearly established that 90% of the pilots who responded to this questionnaire, who had greater than 150 flying hours with NVG’s, reported neck pain and some form of disability. Collectively, these reports and questionnaires demonstrated that “neck injuries range from relatively minor to serious impairments”, and in some cases, the grounding of pilots for years. The majority of research to date had used fighter pilots that typically experience gravitational forces greater than 4 Gz. However, limited quantifiable and objective scientific data is available on pilots that are exposed to gravitational forces (Gz) less than 2 Gz, such as that typically experienced by the CH146 Griffon Pilots and Flight Engineers. Until the inception of this study, limited physiological data was available to the CF Military to provide guidance for their aircrew using NVG equipment.

The rationale for the proposed research study is therefore based on the observations and conclusions from the above-cited reports including the following information:

1. “The aim of this NVG-Induced Neck Strain Study was to identify/present a program that will incorporate all of the necessary strategies for the crew to succeed in reducing the occupational stress and injuries to the neck. Imbedded in the aim is a realization that the origin or cause of these injuries may be multi-faceted, and therefore the remediation should be multi-faceted or perhaps interdisciplinary (medical intervention, physical education, physical fitness, wellness).” (6600-1 (FSD) Physical Fitness Training Program – 403 SQN Instructor Pilots & Flight Engineers, 13 May 2002).

2. “Night Vision Goggle-Induced neck strain is a major concern for the CH146 Griffon fleet.” (Presentation - NVG-Induced Neck Strain Study, Capt Jameel Adam and Mr. Bill Fraser - DRDC Toronto, 9 March 2004).

3. “Determine ways to reduce/mitigate neck strain problems in the CF rotary and fixed wing communities. The emphasis at this time should be directed at the CH146 Griffon.” (DRDC Brainstorming Session 9 Mar 2004 @ DRDC, Toronto).

4. “Determine what kit can be attached to the helmet without hurting pilots, and provide guidance regarding the medical implications of exceeding the baseline limits as required for operational reasons.” (DRDC Brainstorming session 9 Mar 2004 @ DRDC, Toronto).
These observations and conclusion are extremely important as they have both a short-term and long-term impact on the safety of the pilot and crew. Pain and fatigue affect judgment and reduce mental vigilance.

Therefore, this research served as the initial study Phase (I) to collect quantifiable and objective research data to try and solve some of the issues and problems associated with NVG use in helicopter personnel. Specifically, non-invasive near infrared spectroscopy was used to monitor muscle oxygenation and haemodynamic changes during both Day and Night missions (CH146 Griffon Simulator) to examine the fatigue characteristics of the neck musculature that is associated with neck strain as a result of chronic use and wearing NVG equipment. This was the first study of its kind, to our knowledge, to collect muscle oxygenation and blood volume data during flight simulation in RW pilots with and without NVG equipment.

b) Purpose of project:

The purpose of this research project was to collect quantifiable physiological (muscle oxygenation, oxygen saturation) data, and to provide evidence-based research for the diagnosis of muscle neck strain and fatigue. This was based, in part, on the recommendations of the results obtained from the NVG-Induced Neck Strain Questionnaire Study, conducted by DRDC in August 2001, and the CF and DRDC desired deliverables.

c) Objectives of project:

- To test the utility of using NIRS to assess NVG-Induced Neck Strain in RW Helicopter Pilots in the CH146 Griffon Simulator.

- To collect quantifiable physiological research data (muscle oxygenation, blood volume changes) on the Trapezii Muscles that are involved in NVG-Induced Neck Strain.

- To provide evidence-based research for the diagnosis and prognosis of muscle neck strain and fatigue in RW pilots.

d) Scope and limits of project:

The scope of this study was limited to collecting physiological (NIRS) data in the CH146 Griffon Simulator on RW Pilots only. Therefore the following results are directly applicable to these simulated missions, and provide an indication of what is occurring in the neck musculature under controlled conditions (temperature, vibration, Gz forces) in the Simulator. No data was collected on Flight Engineers, but future studies must include this group of airforce personnel. Due to time constraints with the pilots (preparation time), electromyographical (muscle recording) data was not collected but needs to be included in future studies. This recommendation was also confirmed in conversation with the biomedical scientists at USAARL in Ft Rucker AL during the recent research visit by the PI (Dr. Neary).
e) **Highlight the research team**

The research team was very pleased to have worked with an extremely cooperative group of pilots (pilots from all CF SQN participated in this research). As a research practitioner this is paramount in collecting clean and useable data. Therefore, we are confident that the data collected is reliable and valid, and our interpretation of the results is based on sound quantifiable data. Furthermore, the Flight Instructors were very accommodating in helping us achieve our goals and objectives.

Another highlight of this research project was that it provided a unique opportunity for the Principle Investigator (Dr. Patrick Neary) to traveling to Fort Rucker, AL to visit the US Army Aeromedical Research Laboratory (USAARL). During this visit, Dr. Neary had an opportunity to observe, participate, and discuss NVG-Induced Neck Strain research experimentation with the USAARL biomedical research scientists. It was rewarding to learn that our research team is approaching this NVG issue with advanced technology and innovative research ideas (the use of NIRS technology to examine muscle metabolism and physiology). The USAARL biomedical scientists also expressed willingness and commitment to collaborate on future research studies (see attached email from Dr. John Crowley). This will be advantageous and mutually beneficial for future research projects that we will be proposing in Phase II - IV.

f) **Highlight how the findings of the research will impact the CF**

This is the first study, to our knowledge, to collect quantifiable physiological muscle oxygenation and blood volume data on the Trapezius muscles of the neck that are implicated in NVG-Induced Neck Strain. To date, the concerns over neck strain have been reported through survey research (eg. questionnaires), leaving speculation to the dose-response relationship between neck strain and NVG use. Measurement of quantitative physiological responses of the neck muscular provides an empirical basis for this hypothesis. It is our belief that these research findings will have a significant impact on helping to solve the issues related to NVG-Induce Neck Strain, and, this data will serve as a foundation for future research in this area of concern for CF Military. It is the goal of this research program to determine the dose-response criteria of NVG-Induced Neck Strain in order to develop prevention strategies in terms of safety guideline, educational awareness and training protocols for NVG use.

2) **Respondents:**

The respondents in this project included CF Griffon Helicopter Pilots and Flight Instructors. A list of the airborne divisions and the number of pilots from each division are listed below (3.1. Subjects).

3) **Procedures:**

NVG-Induced Neck Strain in not a simple problem to rectify but rather involves a multitude of factors that must be considered to determine its full impact. For example, the time...
interval (days) between flight operations, the number of consecutive days flying, the optimal numbers of days flying interspersed with optimal number of days rest, and wearing NVG vs. not wearing NVG equipment are just a few factors of concern and that need to be addressed. This results in a significant number of combinations and permutations of factors to assess. However, the major thrust of this initial research was to collect quantifiable physiological (NIRS) data to assist in addressing questions that have surfaced from the DRDC Questionnaire. It was therefore decided by the research team, in consultation with Maj Dan Veillette (SQN 403), that the initial research data collection includes Day (non-NVG) vs. Night (NVG) missions in the CH146 Griffon Simulator.

3.1. Subjects:

Signed informed consent was obtained from all participants in accordance with the University of New Brunswick Research Ethics Board for research involving human subjects. Complete confidentiality was upheld with only the Principal Investigators, Research Assistants and CF Military personnel directly involved in the project having access to the identity of the individuals involved. A total of $N=33$ CH146 Griffon 1 Wing Pilots from all CF SQN were tested for this project, using the Griffon Simulator and Training Centre at CFB Gagetown. This provided greater content and criterion-related validity making the results applicable to pilots in other squadrons and similar occupations (e.g. Sea King aircrew, Flight Engineers). The breakdown of pilots was as follows:

<table>
<thead>
<tr>
<th>squadron</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQN 430</td>
<td>N=8</td>
</tr>
<tr>
<td>SQN 408</td>
<td>N=6</td>
</tr>
<tr>
<td>SQN 427</td>
<td>N=8</td>
</tr>
<tr>
<td>SQN 403</td>
<td>N=5</td>
</tr>
<tr>
<td>SQN 400</td>
<td>N=2</td>
</tr>
<tr>
<td>SQN 438</td>
<td>N=2</td>
</tr>
<tr>
<td>SQN 444</td>
<td>N=2</td>
</tr>
</tbody>
</table>

3.2. Methodology:

Anecdotal reports from the 403 SQN (Maj Dan Veillette), and information from the DRDC Brainstorming Session (9 March 2004) have stated that consecutive days of flying create the most significant problems. However, quantifiable physiological data has not been collected previously on RW Pilots to verify whether consecutive days have a significant cumulative effect on muscle properties (muscle oxygenation and blood volume changes). Therefore, as stated previously, this initial project was designed to collect quantifiable physiological data and to determine the utility of using NIRS in the future to investigate solutions to this NVG-Induced Neck Strain issue.

Study Design:
1. Simulation flight (CH146 Griffon): Average flight time $\approx 2$ hrs.
   a. Day Mission – Helmet only, no NVG equipment used
   b. Night Mission – Helmet with NVG equipment used
   c. Day and Night missions were identical to ensure comparison of data
2. NIRS (muscle oxygenation and blood volume changes) recorded and monitored (Trapezii muscles bilaterally).

3. Sample, N=33 (RW Pilots and Flight Instructors, see above) were assessed, with each pilot performing 2 trials (Day and Night).

The following dependent variables were collected using NIRS monitoring of the Trapezi muscles:

1. **Total Oxygenation Index (TOI) (%).** TOI is a measure of the amount of oxygen that is bound to haemoglobin (the oxygen carrying structure in the blood) when blood reaches the muscle.

2. **Deoxygenated Hemoglobin (HHb; μm).** HHb represents the amount of Hb present in the area of interrogation of the muscle that is not bound with oxygen. This provides an indication of how much oxygen that has been released from Hb into the muscle cells.

3. **Oxygenated Hemoglobin (O2Hb; μm).** O2Hb provides an indication on how much Hb is arriving at the site of measurement that is bound with oxygen.

4. **Total Hemoglobin (tHb; μm).** tHb is an indirect measure of blood flow to the muscle. It is calculated by adding together the deoxygenated and the oxygenated Hb signal. Therefore, it reflects the blood volume at that particular level at which in being investigated (“probed”)

### 3.3. Statistical Procedures:

Data were compiled and analysed using SPSS v.10 (SPSS, USA). Data for all variables were graphed by subject to identify any outlying values and the appropriate files were manually inspected to determine potential causes for the outliers. Those outlying data points for which manual inspection indicated an erroneous reading (due to movement artefact, signal overflow or underflow, or loss of probe adhesion) were removed. Two subject files were removed completely from the data set for the final analysis due to numerous complications such as missing data and unreliable values within the data present (N=31).

One-way ANOVA was conducted to determine the existence of any differences between variables for those subjects who used a counterweight and those who did not use a counterweight during NVG flights. The results of this ANOVA led to a separate analysis that divided the group into counterweight users (NVG-CW; N=25) and non-counterweight users (NVG; N=6). A split-plot repeated-measures univariate ANOVA (spANOVA) was conducted on the NVG-CW data sets (N=25) to control for the individual variability within the data set and to identify differences in the variables under different conditions. Results are also be presented that compared NVG-CW vs. NVG in Figures 9-11, and Tables 9-11.
4) **Results:**

We successfully monitored muscle oxygenation and blood volume changes in the neck musculature (i.e., Trapezii m) that is most affected by use of NVG equipment. This has been verified from recent correspondence with biomedical scientists at USAARL in Ft Rucker, AL, which showed that the Trapezii, Sternocladomastoid, and Splenus Capitis muscles are mostly recruited during simulated helicopter operation missions (Barazanji & Alem 2004).


The major highlights and achievable outcomes of this research project are illustrated in the following Tables and Figures. A summary of the major results include:

a) **Comparison of Day vs. Night missions illustrated that differences exist in the dependent variables examined (muscle oxygenation, deoxygenation, oxygen saturation).**

Due to the fluctuations in actual mission times from subject to subject, mission times were standardized to a percentage of the total flight time (i.e. 10% of mission time, 20% of mission time, etc) to allow for comparison between missions (Day vs. Night) and between subjects. spANOVA analysis indicated that significant differences (p<0.05) did exist between conditions (Day vs. Night missions) when controlling for individual subject differences for all four dependent variables collected (TOI, tHb, HHb & O2Hb). Significant differences were also found as a function of time when controlling for individual subjects. **Figure 1, Figure 2, Figure 3** and **Figure 4** provide a summary of the results for each variable over the course of the Day and Night missions. The solid vertical (black) line at 20% of mission time in all figures indicates the average approximate location of the event marker corresponding with the movement of the NVG equipment from their upright position on the helmet to the lowered operational position for flight. This change in position for the NVG equipment may have effected the moment of force the neck musculature experienced during the mission. The solid black line at 70% of mission time indicates the average approximate location of the event marker corresponding with the return of the NVG equipment from the lowered operational position to the upright position (13/25 subjects performed this maneuver, with the remaining 12 subjects completing the final 20-30% of the test with the NVG’s in the lower operational position). It should also be noted that no recovery time data is presented in these Figures as the pilots were anxious to leave the simulator after their lengthy missions were finished. Therefore, recovery data was not collected and thus sufficient time was not allowed for the dependent variables to return to baseline.

**Table 1, Table 2, Table 3** and **Table 4** provide a summary of the interactions between the fixed factors used in the spANOVA and each dependent variable. Statistical significance was determined as p≤0.05 and the strength of the main effect was determined as when eta (η²) was ≥0.2.
Figure 1 – Average Total Oxygenation Index (TOI) Values for Trapezius Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

Table 1 - Split Plot ANOVA Results for TOI by Subject, Mission Condition and Time (N=25).

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>0.000</td>
<td>0.822</td>
</tr>
<tr>
<td>Condition</td>
<td>0.471</td>
<td>0.019</td>
</tr>
<tr>
<td>Time</td>
<td>0.000</td>
<td>0.046</td>
</tr>
<tr>
<td>Subject x Condition</td>
<td>0.000</td>
<td>0.121</td>
</tr>
<tr>
<td>Condition x Time</td>
<td>0.638</td>
<td>0.007</td>
</tr>
</tbody>
</table>

A summary of the spANOVA results is contained in Table 1 above and an overview of the average TOI responses under both mission conditions is provided in Figure 1. Analysis of TOI by spANOVA indicated that, while the effect size was small, significant differences existed when the factorial model used subject by condition as interactive factors. Independently, time and subject provided significant differences with the factorial model using subject as a factor returning a large effect size (or eta).
**Figure 2** – Average Total Hemoglobin (tHb) Values for Trapezius Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

![Graph showing average total hemoglobin (tHb) values for trapezius muscles during day and night missions.](image)

**Table 2** - Split Plot ANOVA Results for tHb by Subject, Mission Condition and Time (N=25)

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>0.005</td>
<td>0.752</td>
</tr>
<tr>
<td>Condition</td>
<td>0.129</td>
<td>0.082</td>
</tr>
<tr>
<td>Time</td>
<td>0.000</td>
<td>0.057</td>
</tr>
<tr>
<td>Subject x Condition</td>
<td>0.000</td>
<td>0.128</td>
</tr>
<tr>
<td>Condition x Time</td>
<td>0.723</td>
<td>0.006</td>
</tr>
</tbody>
</table>

**Figure 2** provides an overview of the average tHb (an estimate of total blood volume to the trapezius muscles) responses over the course of the Day and Night missions, and **Table 2** provides a summary of the statistical differences between tHb values analyzed by subject, condition and time. **Figure 2** indicates that blood volume increased at a reasonably consistent rate over the duration of the Night missions. A shallower slope is presented by the data from the Day missions. This indicates that while a greater blood volume was present in the trapezius muscles during the later stages of the mission as compared to the outset of the mission, the increased demand for blood flow was not as large the demand over the course of the Night.
missions. **Table 2** lends statistical credence to these findings. When spANOVA by subject and condition was conducted, statistical significant differences in tHb results were found.

Furthermore, it appears as if the position of the NVG equipment on the helmet does play a role in determining the level of physiological stress experienced by the Trapezius muscles. The trend in this data set indicates that blood volume is increasing greater during the Night mission after the NVG equipment is put into the operational (down) position (20% Time). This increased blood volume persists until about 40% Time.

**Figure 3** – Deoxygenated Hemoglobin (HHb) Values for Trapezius Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

![Deoxygenated Hemoglobin (HHb) Values for Trapezius Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).](image)

**Table 3** - Split Plot ANOVA Results for HHb by Subject, Mission Condition and Time (N=25).

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>0.000</td>
<td>0.823</td>
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<tr>
<td>Condition</td>
<td>0.794</td>
<td>0.003</td>
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<tr>
<td>Time</td>
<td>0.321</td>
<td>0.010</td>
</tr>
<tr>
<td>Subject x Condition</td>
<td>0.000</td>
<td>0.095</td>
</tr>
<tr>
<td>Condition x Time</td>
<td>0.509</td>
<td>0.008</td>
</tr>
</tbody>
</table>
**Final Report – NVG Induced Neck Strain and Fatigue**

**Figure 3** provides an overview of the deoxygenated (HHb) signal over the course of the Day and Night missions. **Table 3** indicates that statistically significant spANOVA results for differences in HHb values exist for subject and for subject by condition. However, other statistically significant differences by factor in HHb results were not found.

HHb values appear to decrease after the NVG equipment is lowered to the operational position at Time 20% and continues to decrease until Time 70%, the time at which 13 subjects returned the NVG equipment to the non-operational upright position. At this time, it can be hypothesized that the moment caused by the operational location of the NVG equipment may have caused muscle contractions in the Trapezii that resulted in some manner of occlusion. The HHb results during the Night missions after Time 70% could therefore be indicative of recovery following this occlusion. However, this is an important issue and must be re-examined in future experimentation before a definitive explanation can be provided.

**Figure 4** – Oxygenated Hemoglobin (O2Hb) Values for Trapezii Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

**Figure 4** graphically presents the O2Hb values over the course of the Day and Night missions. O2Hb values increased over the course of the missions to Time 50% before the slope leveled off under both conditions. However, at Time 70% in the Night missions, the slope of the results increased again until mission termination. Time 70% corresponds with the timing of the change of position of the NVG equipment on the helmets of the pilots being monitored by the NIRS. **Table 4** indicates that statistically significant differences exist within the O2Hb results when analyzed by spANOVA by subject, by time and subject by mission condition. These results continue to indicate a difference in physiological stress at the Trapezii muscles between Day and Night missions and over the course of the missions.
The factors subject, time and mission condition were found to be important in determining differences within the physiological variables measured by NIRS under both Day and Night mission conditions. Butler’s (1992) review of literature in his PhD dissertation indicated that helicopter pilots experience a great deal of vertebral muscular fatigue and eventually develop vertebral structural abnormalities as a result of their exposure to constant workplace vibration. A majority of this research focused upon the lumbar region of the spinal column and used EMG signals to evaluate the fatigue. Changes in NIRS signals from the outset to the termination of missions under either Day or Night conditions may be indicative of this fatigue at the cervical spinal level and indicative of the utility of NIRS equipment in measuring this fatigue at the cervical level.


b) Comparison of right vs. left Trapezius neck muscles (side differences in neck musculature).

spANOVA analysis indicated the existence of significant right and left muscle (side) differences during Day and Night missions when analyzed by subject, by time and by subject and time. Figure 5 below illustrates the right and left Trapezius muscle differences for TOI. Again, at Time 20%, the change in position of the NVG equipment caused an increase in the slope of the TOI graph. While elevated as compared to the left Trapezius during the Day flight, the right trapezius’ TOI graph appears consistent over the course of the mission. The right and left Trapezius results for the TOI share remarkably similar starting points before the TOI values for the right Trapezius begin to increase over the course of the mission.
Figure 5 – Total Oxygenation Index (TOI) Values for Left and Right Trapezius Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

Table 5 - Split Plot ANOVA Results for TOI by Subject, Mission Condition, Side and Time (N=25)

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject x Side</td>
<td>0.000</td>
<td>0.513</td>
</tr>
<tr>
<td>Condition x Side</td>
<td>0.931</td>
<td>0.000</td>
</tr>
<tr>
<td>Subject x Condition x Side</td>
<td>0.000</td>
<td>0.800</td>
</tr>
</tbody>
</table>

Table 5 indicates that no significant differences were found between mission condition (Day vs. Night) for a particular side. This differs from the results of the other variables measured, analyzed, and reported in subsequent sections of this results section. This differing finding is likely the result of the reporting of the results as a qualitative unit (percent) and not as a quantitative unit (μm) as used by the other variables for which significant differences between measurements by side and mission conditions were found.
**Figure 6** – Total Hemoglobin (tHb) Values for Left and Right Trapezius Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

![Graph showing tHb values over time for Day and Night missions with and without NVG.]

**Table 6** - Split Plot ANOVA Results for tHb by Subject, Mission Condition, Side and Time (N=25)

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject x Side</td>
<td>0.000</td>
<td>0.430</td>
</tr>
<tr>
<td>Condition x Side</td>
<td>0.510</td>
<td>0.001</td>
</tr>
<tr>
<td>Subject x Condition x Side</td>
<td>0.000</td>
<td>0.718</td>
</tr>
</tbody>
</table>

Significant side differences by time and by subject were identified by spANOVA for tHb results over the course of Day and Night missions. During both Day and Night missions and as illustrated in **Figure 6**, the right Trapezius muscle received more blood volume as compared to the left Trapezius and this blood volume increased as mission length increased. It should be noted that the starting values for both sides under both mission conditions were comparable. This consistent starting value and the subsequent changes further indicate that side and mission condition differences do exist within the Trapezii muscles.

When analyzed for subject by side (**Table 6**), significant differences between tHb for Day and Night mission conditions were found with a large effect size (η² = 0.718). However, side by mission condition analysis of tHb results did not provide statistically significant differences.
**Figure 7** – Deoxygenated Hemoglobin (HHb) Values for Left and Right Trapezii Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

HHb results over the course of the missions under both Day and Night conditions and for left and right side responses are reported in **Figure 7**. Again, similar initial values were found for the four graphs (two Trapezii muscles and two mission conditions) with changes occurring over the course of the missions. The noticeable period of decreasing HHb values observed in **Figure 3** is more prominently visible in **Figure 7** and is caused by a decrease in HHb signal in the right Trapezius during the Night missions. Again, a substantial side difference has been observed and occurs at the simultaneously (Time 70%) with the change in position of the NVG equipment.

**Table 7** - Split Plot ANOVA Results for HHb by Subject, Mission Condition, Side and Time (N=25)

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>( \eta^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject x Side</td>
<td>0.000</td>
<td>0.455</td>
</tr>
<tr>
<td>Condition x Side</td>
<td>0.040</td>
<td>0.005</td>
</tr>
<tr>
<td>Subject x Condition x Side</td>
<td>0.000</td>
<td>0.752</td>
</tr>
</tbody>
</table>

**Table 7** indicates that significant differences were found when analysis was conducted for side by subject, side by condition, and side by subject by condition. Both side by subject and side by subject by condition analyses provided large effect sizes (\( \eta^2 = 0.455 \) and \( \eta^2 = 0.752 \), respectively).
Figure 8 – Oxygenated Hemoglobin (O$_2$Hb) Values for Left and Right Trapezius Muscles of CH-146 Pilots during Simulated Day and Night Missions (N=25).

O$_2$Hb results during Day and Night missions are presented in Figure 8. Similar starting points can again be observed with changes in the O$_2$Hb curves occurring over the course of the missions under both mission conditions. For the most part, the graphs for Day and Night missions for the right Trapezius were comparable. The graphs for Day and Night missions for the left Trapezius were similar to each other but had smaller amplitude as compared to the results from the right Trapezius. The average right Trapezius graph during the Night missions displays a steep increase from the initial measurement that is maintained for the duration of the mission. While the left Trapezius displays a similar slope initially, the O$_2$Hb values have almost returned to baseline levels by Time 20% (change in position of the NVG equipment from upright to operational) and a flat slope is observable for a large proportion of the mission. After Time 70% (change in position of the NVG equipment), the slope on the left Trapezius signal during the Night mission begins to increase at a slope that is nearly parallel to that of the signal from the right Trapezius.

Table 8 - Split Plot ANOVA Results for O$_2$Hb by Subject, Mission Condition, Side and Time (N=25).

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject x Side</td>
<td>0.000</td>
<td>0.367</td>
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<tr>
<td>Condition x Side</td>
<td>0.799</td>
<td>0.000</td>
</tr>
<tr>
<td>Subject x Condition x Side</td>
<td>0.000</td>
<td>0.696</td>
</tr>
</tbody>
</table>
Table 8 provides the details of the spANOVA analysis. Significant side differences were for O$_2$Hb results analyzed subject by side and subject by condition by side. Side differences continue to be a prominent statistically significant result under both mission conditions.

Our consistent findings of left and right side (Trapezii muscles) differences correspond with a published report by Lopez-Lopez et al. (2001). The authors used EMG to measure lower back fatigue and found posture contributed to fatigue and side differences with respect to the magnitude of the fatigue. It was noted that pilots of the UH-1 Huey (similar in cockpit orientation to the CH-146 Griffon and replaced by the CH-146 Griffon in the CF) experienced greater levels of measurable fatigue on the right side as compared to the left side of the lumbar spine musculature. This issue will be examined further when NIRS and EMG are combined in future studies.


c) Comparison of the use of counterweights used (vs. no counterweights on helmets) to re-establish Centre of Gravity.

Of the 33 subjects who participated in this research study, 2 sets of data were removed due to excessive missing or outlying data points. Of the remaining 31 subjects, 25 used the counterweight (CW) equipment provided by the CF while operating with NVG equipment. Given the disproportionate populations (NVG-CW = 25; NVG = 6), a test of the homogeneity of variance was performed and only TOI returned a Levene’s statistic value that was significant. As such, it was deemed acceptable to perform a one-way ANOVA on the tHb, HHb and O$_2$Hb results to investigate for differences between the results for the NVG-CW and NVG groups.

The results of the spANOVA for tHb, HHb and O$_2$Hb are reported in Table 9, Table 10 and Table 11. The small subject pool of individuals who did not employ CW equipment was surprising to the research team and it would be beneficial to test additional individuals in the NVG group. However, given the scope and breadth of this sample population, it does appear that the majority of RW pilots use CW equipment and anecdotal reports from the 33 subjects indicate that many pilots would not consider flying without this equipment. The general feeling is the CW equipment either prevents NVG-induced neck pain or moderates the intensity of NVG-induced neck pain.
Figure 9 – Total Hemoglobin (tHb) Values for Left and Right Trapezius Muscles of CH-146 Pilots Using Counterweight Equipment (N=25) and Not Using Counterweight Equipment (N=6) during Simulated Night Missions.

Figure 9 provides a graphical summary of the results of tHb for the pilots employing CW equipment (NVG-CW, N=25) and those not employing CW equipment (NVG, N=6). The initial values are remarkably similar bilaterally in both populations. However, the right Trapezius of the NVG group displayed a rapid increase in blood volume early in the mission and maintained an elevated tHb level as compared to the right Trapezius in the NVG-CW group. The left Trapezius results, however, indicate that the left Trapezius of the NVG group receives a smaller blood volume as compared to the left Trapezius of the NVG-CW group.

Table 9 - Split Plot ANOVA Results for tHb by Counterweight, Subject, Side and Time (N=31; NVG-CW n=25, NVG n=6)

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>0.859</td>
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</tr>
<tr>
<td>CW x Subject</td>
<td>0.000</td>
<td>0.308</td>
</tr>
<tr>
<td>CW x Side</td>
<td>0.000</td>
<td>0.083</td>
</tr>
<tr>
<td>CW x Time</td>
<td>0.000</td>
<td>0.059</td>
</tr>
</tbody>
</table>

Table 9 indicates that statistically significant differences in tHb results exist when analyzed CW by subject, CW by side and CW by time. However, given the imbalance in population sizes
and the small effect sizes reported, it would be best to interpret these results simply as being indicative of a need for further research into the benefits associated with use of CW while wearing NVG equipment. It is our intent to investigate this issue further in our proposed research in Phase II and Phase III.

**Figure 10** – Deoxygenated Hemoglobin (HHb) Values for Left and Right Trapezius Muscles of CH-146 Pilots Using Counterweight Equipment (N=25) and Not Using Counterweight Equipment (N=6) During Simulated Night Missions.

_Figure 10_ provides a visual summary of the results for HHb with similar highlights to the tHb results in _Figure 9_. The initial staring values are comparable and while the right Trapezius signal for the NVG group is higher as compared to the NVG-CW group, the left Trapezius signal is lower as compared to the same signal in the NVG-CW group. Interestingly, the graphed valley observable at Time 70% seen in _Figure 3_ and _Figure 7_ is again present but attributed to the NVG-CW population. Given the imbalance in the populations, it would not be prudent at this time to comment on this result other than to use this finding to motivate further research into the coupled use of CW and NVG equipment.

**Table 10** - Split Plot ANOVA Results for HHb by Counterweight, Subject, Side and Time (N=31; NVG-CW n=25, NVG n=6).

<table>
<thead>
<tr>
<th>Fixed Factor(s)</th>
<th>p-value</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>0.488</td>
<td>0.017</td>
</tr>
<tr>
<td>CW x Subject</td>
<td>0.000</td>
<td>0.315</td>
</tr>
<tr>
<td>CW x Side</td>
<td>0.000</td>
<td>0.058</td>
</tr>
<tr>
<td>CW x Time</td>
<td>0.000</td>
<td>0.014</td>
</tr>
</tbody>
</table>
Table 10 also indicates that statistically significant differences in tHb results exist when analyzed CW by subject, CW by side and CW by time. However, given the imbalance in population sizes and the small effect sizes reported, it would again be best to interpret these results simply as being indicative of a need for further research into the benefits associated with use of CW while wearing NVG equipment.

Figure 11 – Oxygenated Hemoglobin (O$_2$Hb) Values for Left and Right Trapezius Muscles of CH-146 Pilots Using Counterweight Equipment (N=25) and Not Using Counterweight Equipment (N=6) during Simulated Night Missions.

Figure 11 provides a visual summary of the results for O$_2$Hb with similar highlights to the tHb and HHb results in Figure 9 and Figure 10 respectively. The initial staring values are comparable and the right trapezius signal for the NVG group is higher as compared to the NVG-CW group. However, the left Trapezius signals for both NVG-CW and NVG populations were similar for the course of the mission. Table 11 also indicates that statistically significant differences in O$_2$Hb results exist when analyzed CW by subject, CW by side and CW by time. However, it is difficult to comment further on the results other than to suggest that a definite need for physiological research into the benefits to, and potential risks of, crewmembers associated with the use CW equipment during NVG flights in the CH-146.
This research endeavoured to be non-disruptive to the pilots monitored during the training missions. As such, pilots were not asked to operate under abnormal conditions as compared to what they were accustomed. This included not requesting that individual pilots remove their counterweights in order to obtain the balanced sample populations that would have allowed for a more robust statistical analysis of the NVG-CW and NVG results. However, these preliminary results do suggest that further phases of our research should consider NVG-CW and NVG conditions as two variables worthy of serious investigation.

d) In addition to the major findings stated above, we will be able discuss a number of importance relationships from this data set that was not initially expected. Because of the experimental design of this project, we were able to collect additional data that will allow us to examine a number of confounding variables and provide a clearer picture of what is happening during in-flight simulation. However, because this data collection was not expected in the original proposal submission, we have not allowed sufficient time to undertake these analyses at this particular time. However, these will be analysed within the next month. These analyses will have important implications for our future work in Phase II and III, and will contribute to the overall project. These analyses will include:

- NVG flight experience (hours) vs. NIRS data (muscle oxygenation)
- Fitness level of pilots vs. NIRS data
- Level of neck/shoulder disability or injury (if any) vs. NIRS data

5) Discussion:

We have successfully completed Phase I of what we believe must be a four-part phase to this research program (Phase I to IV) to solve the issues related to NVG-Induced neck strain in RW personnel. It is immediately apparent from the results provided above that much more work is needed in this area of research.

It should be noted that we did not receive confirmation that our proposal for funding was successful until 15 June 2004, and, due to the already established schedule and time constraints
for the CH146 Griffon Flight Simulator at CFB Gagetown, we were not able to collect data until 16 August 2004. Therefore, we successfully completed this phase of the project in seven (7) months, with this project being on-time and under budget.

A review of the related literature is currently being compiled and this will be updated on a continuous basis. A preliminary examination of the current literature documents that there is a lack of quantifiable scientific research on NVG-Induced neck strain. Also, there is a lack of good scientific research data that has examined the effects of exercise training programs to ameliorate this significant problem in RW pilots.

Contact with the US Army Aeromedical Research Laboratory (USAARL) in Ft Rucker AL, has been established with the recent trip by Dr. Neary (February 3-5, 2005) to discuss future research collaboration. USAARL biomedical research scientists have expressed a willingness to share equipment and information regarding NVG issues obtained on their military pilots. It is also anticipated that a major research project to determine the effects of different exercise training programs will be coordinated with USAARL (see attached email, Dr. John Crowley).

Significance of Research Findings:

- Muscle oxygenation and blood volume changes indicate that the physiological properties of the muscle can be monitored using NIRS. This was an extremely important finding for the next Phases (II, III, IV) of our proposed NVG program. The current results indicate that these physiological parameters must be monitored before, during and after exercise assessment and exercise training programs to better understand the biomedical issues involved in NVG-Induced Neck Strain, because our data showed that physiological difference exist between Day (non-NVG use) and Night (NVG use) missions when monitoring the trapezii muscles of the neck.

- Our research also confirms the need for the development of an NVG-LAP (Laboratory Assessment Protocol) Test which will be implemented as part of Phase II. It is hypothesised that this NVG-LAP Test will serve as a diagnostic test for NVG-Induced neck strain related injuries, as well as a test to provide baseline data for novice pilots and flight engineers.

- The physiological muscle property changes (i.e., differences between right and left Trapezius muscles) suggest that exercise training programs may be beneficial for these RW pilots within the CF Military, and possibly for all personnel that may be expected to use NVG equipment in the future. This must be investigated and will be the major objective of Phase III of our NVG program.

- The current data base of physiological data will serve as the initial set of results from which to compare individual pilots in the future. Future data collected will be added to this pool of data to form an on-going data base for comparison, especially for those pilots that have not yet used or experienced NVG equipment use on a habitual basis.
The present data confirms the need to examine NVG-Induced Neck Strain from not only a physiological basis, but also from a biomechanical and ergonomic (video time-motion analysis) perspective. In consultation with biomedical scientists at USAARL in Ft. Rucker AL, it is also imperative that electromyographical (EMG) activity of the muscle be monitored during all testing and assessment. This will be performed simultaneously with NIRS data collection in the proposed future studies, and will likely include monitoring other muscle groups besides the Trapezius (i.e., Sternocladomastoid and Splenus Capitius).

Completion of Phase I confirms the need to have our physiological equipment airborne to collect actual on-board mission data for comparison with the simulated missions in the CH146 Griffon Flight Simulator, and to collect data on flight engineers activities. This inclusion would also assist to validate our data and determine the relationship between actual and simulated missions. Our future proposal will include this as an objective for Phase II of the NVG program. However, this part of Phase II will not delay us in moving forward if there is a delay in receiving authorization to include our NIRS/EMG equipment on-board. Furthermore, we are currently discussing future collaboration with USAARL regarding this issue. It is anticipated that we will also have access to US pilots and flight engineers during on-board operation using their Blackhawk UH-60 Biomedical Operation Helicopter. This Blackhawk helicopter is dedicated for biomedical research at Ft. Rucker, AL. This will allow us to perform more testing on more pilots and flight engineers, and also to make comparisons between the operations of the CF Griffon and the US Blackhawk.

As stated above on a number of occasions, further research (Phase II - IV) is imperative to help solve the issues related to NVG-Induced Neck Strain in RW Pilots and Flight Engineers (see Phase descriptions below), and to work toward a preventative strategy and solutions.

Proposed Time-line of the NVG-Induced Neck Stain Research Program:

- **Phase II**: 9 months (April 2005 – December 2005)
- **Phase III**: 9-12 months (January 2006 – September/December 2006)
- **Phase IV**: 12 months (January 2007 – December 2007)

Because of our research and the novel findings with respect to the effects of NVG equipment on neck muscular function, other issues have surfaced and must be investigated more thoroughly in the next phases of our program. The following are examples of projects that we feel must also be considered and addressed to secure solutions to the issues that surround NVG-Induced Neck Strain:

- Recovery period during measurement- during the collection of physiological data, it will be important in the future to have the pilots and flight engineers sit
quietly for 5-10 minutes to observe whether the dependent variables examined return to baseline.

- **Counterweighting**—now that we have quantifiable physiological data, this issue of counterweighting vs. non-counterweighting appears to be an important factor to consider and examine in our future research. This will be one of the objectives that will be investigated in Phase II of our NVG program.

- **Muscle side differences**—our data demonstrates that left and right muscle side differences exist. This appears to be independent of the position which the pilot is sitting in the cockpit. Future research will examine this issue before recommendations can be made regarding ergonomic changes to the cockpit in the future.

- **Consecutive days flying**—in discussion with a number of the pilots and instructors, and from our observations, it is also important that we examine NVG related response of the muscle during consecutive days (2-5) of flying. This will help to address the effects of cumulative fatigue.
Appendix B: Exercise Training Programs – Paper Submitted for Scholarly Publication; Abstract Only

After this paper is published we will provide a copy to DND for their files.

Abstract:

The prevalence of neck pain related to the occupational environment of flight in CH-146 Griffon aircrew has been identified in the range of 81-84%. In an attempt to mitigate this problem, we quantified the adaptations of cervical muscle isometric strength using a 12-week training program. Subjects were recruited on a volunteer basis from Canadian Forces (CF) CH-146 Griffon aircrew in Gagetown, NB, and randomized into either a general neck strength and muscle coordination training program (CTP; n=10), or a neck muscle resistance training program (ETP; n=11). Volunteers for a non-treatment control (NTC; n=8) were recruited from CH-146 Griffon aircrew base in Valcartier, PQ. Baseline assessments were performed using isometric contractions to determine maximal voluntary contraction (MVC) strength of the cervical musculature (flexion, extension, left lateral flexion and right lateral flexion). Endurance capacity was measured using isometric submaximal contractions to fatigue at a resistance level of 70% of their MVC values. The ETP subjects performed dynamic contraction at 30% of their MVC in the four testing directions using a head harness and Thera-band tubing. The CTP consisted of exercises that focused on strengthening the deep cervical musculature using weight of the head as resistance, progressing to exercises that incorporated the superficial cervical muscles using a resistance load of 30% MVC. After completion of the 12-week intervention, the CTP produced the greatest improvement in maximal force reaching statistically significant for flexion (13.76%) and right lateral flexion (15.92%). However, the ETP achieved the only significant increase when compared to the NTC in right lateral flexion (14.35%). Improved times to fatigue were achieved by the CTP for flexion, \( t(9) = 3.04, p = 0.01 \), left lateral flexion, \( t(9) = 2.1, p = 0.03 \) and right lateral flexion, \( t(9) = 3.51, p = 0.00 \). When compared to the NTC only, left and right lateral flexion improved significantly. The ETP produced substantially smaller improvements, none of
which were significant. For the area under the endurance force curve the CTP produced significant right phase shifts for flexion, $t(9) = 2.67, p = 0.01$ and right lateral flexion, $t(9) = 2.78, p = 0.01$. When compared to the NTC, significant phase shifts were found for left and right lateral flexion in the CTP and in right lateral flexion for the ETP. Both the ETP and the CTP achieved clinically important reductions in self-reported neck pain on a visual analog scale (VAS), with the greatest decreases reported for ‘pain at worst’. A significant reduction in self-reported neck pain was achieved by the CTP for ‘pain in general’ ($t(9) = 2.47, p = 0.02$) and ‘pain at worst’ ($t(9) = 2.06, p = 0.04$), compared to the ETP, where the reduction was limited to ‘pain at worst’ ($t(10) = 2.18, p = 0.03$). A relative pain reduction of 50% was also used to determine whether the treatment was successful in reducing the occurrence of neck pain. The ETP achieved a 50% reduction in VAS scores in 18% of the subjects for both ‘pain at present’ and ‘pain in general’ and in 45% of the subjects for ‘pain at worst’. This decrease was achieved by 30% of the CTP cohort for ‘pain at present’, 40% for ‘pain in general’, and 60% for ‘pain at worst’. The provision of an ETP and CTP three times a week for 12 weeks resulted in a positive trend towards improved maximal isometric force and muscular endurance in the cervical musculature. The greatest improvements were found for those subjects assigned to the CTP treatment. By performing ETP or CTP, participants were able to reduce self-reported neck pain, with the most profound effects occurring for ‘pain at worst’. Future research should be directed toward quantifying the results of the training programs using neuromuscular and metabolic measures.