Night Vision Goggle-Induced Neck Pain in Military Helicopter Aircrew: A Literature Review

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Neck pain occurs at a significant rate in the military helicopter community. It is often attributed to the use of night vision goggles (NVG) and to a number of additional factors such as anthropometrics, posture, vibration, mission length, physical fitness, and helmet fit or load. A number of research studies have addressed many aspects of this epidemic, but an up-to-date and comprehensive review of the literature is not currently available. This paper reviews the spinal anatomy in general and then summarizes what is known about the incidence and prevalence of neck injuries, how the operational environments and equipment may contribute to these injuries, and what can be done to address them from a prevention and/or rehabilitation perspective.

KEYWORDS: cervical spine, myalgia, pilot, NVG, neck injury, rotary wing

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The flight helmet is a vital component of the aircrew protective equipment. The helmet's primary function is to protect the head from impact during a crash landing, a hard landing, or during exposure to other flight hazards,[14,16] but it is also being frequently used as a "mounting platform for numerous combat-essential devices".[14] As a result, devices such as night vision goggles (NVG) or heads-up display (HUD) units are used with increasing frequency. NVG allow pilots to enhance their visual capacity under low light conditions while HUD allow pilots to maintain their line-of-sight without having to look down or away from the horizon in order to obtain information from their instruments during flights. Additional devices, however, come at the cost of the increased mass and also alter the center of gravity of the helmet.[62]

NVG–induced neck strain is an increasing concern among military helicopter communities, including the United Kingdom,[102,103,106] Sweden,[2,90] Holland,[95–97] the United States,[15,33] and Canada.[31,46,80] The point prevalence in general population adults from Canada and the United States is 15% and 14%, respectively;[25,29] the lifetime prevalence of neck pain among the general population of adult Canadians is approximately 67%.[24,25] The prevalence of neck pain among helicopter aircrew is consistently described as higher than the general population[1,4] with varying rates in the published literature. In Australia, the point prevalence is reported as 29%,[88] comparable to the 1-yr prevalence reported in Dutch helicopter aircrew.[97] In Sweden, the 3-mo prevalence of reported neck pain is 57%. In the United Kingdom, the prevalence ranges by squadron from 38 to 81% among helicopter pilots and airload masters[106] while a recent report from the United States Army reveals 58% of helicopter aircrew report neck pain related to flying.[102] The lifetime prevalence of neck pain in Canadian Forces (CF) helicopter pilots and flight engineers operating the CH-146 Griffon helicopter is reported in the range of 81–84% and exceeds 90% among a subset of the population who have logged more than 150 hr of NVG-flight hours during their career.[1] Most concerning, prior injury has proved an excellent predictor of future injury when it comes to the spinal column of helicopter aircrew.[4,88]

The issue of spinal column injuries and discomfort in helicopter aircrew is not new. One of the earliest documented cases predates World War II when a French helicopter test

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pilot recounted an endurance flight as "shaken up in an uncomfortable seat for an hour of flight, the pilot hastens to land and get back to the hangar to take care of his stiff spots".[7] Modern reports began appearing in literature approximately 40 yr ago.[27,83,86] Bowden[11] described back pain in helicopter aircrew as being comparable to that experienced by truck drivers and heavy equipment operators in civilian industries. Early attempts to understand the issue through questionnaire surveying indicated aircrew typically experienced dull pain in the lumbar area during flight and persisting after mission completion.[10] While neck pain and injury had been identified in fixed-wing fighter pilots exposed to high $+G_z$ forces,[63] at the time helicopter aircrew almost exclusively reported back pain, rarely in the neck and shoulder region.[27] Literature related to neck pain and injury in helicopter aircrew did not begin to emerge until later during the 1990s, when unique equipment requirements were needed to accommodate the increasing number of female pilots joining flight operations.[78] Women were perceived as more susceptible to injury due to differences in neck strength and flexibility compared to men, which consequently lead to increased literature related to neck pain and injury in helicopter aircrew.[59]

Lower back pain (LBP) is among the most common occupational health problems[101] and prevalence of LBP in the Canadian and American adult population is 18%[17] and 26%, respectively.[29] LBP is a well-documented issue in helicopter pilots with a lifetime prevalence of 61–80% worldwide.[12,39,88] Findings from an epidemiological review of occupational LBP report helicopter pilots have the highest rates among occupations requiring a seated position for more than half of the workday.[65] Survey data from United States Navy helicopter pilots by Phillips[77] indicate that 88% of pilots report experiencing LPB during at least half of their flights and 34% of these pilots admit that their LBP negatively affects their situational awareness. LBP continues to be more prevalent than neck pain among helicopter aircrew[102] but logic and this review will suggest these injuries are more likely related, as suggested by a recent report,[103] rather than exclusive.

When the spinal column is considered as a whole, helicopter aircrew are at increased risk for chronic injuries of the spinal column related to the specifics of their working environment. This review of literature focuses on these specifics as they pertain to neck injuries but also discusses the related elements of the back pain epidemic that is well documented in this population. The reasoning for this is multifold:

1) The spinal column acts in concert to support the weight of the head in a caudal direction; mass on the head is supported by the cervical spine, which is in turn supported by the thoracic spine, which is further supported by the lumbar and sacral spine as the load is ultimately supported by the pelvic girdle.
2) The posture required to perform occupational duties is one of the most commonly discussed factors in investigations of back and neck injuries in this population.
3) The vibration associated with the working environment, also commonly cited as a stressor, is transmitted and augmented in a rostral direction as found by multiple teams of researchers.

This review will briefly discuss the anatomy of the spinal column, specific hypotheses related to neck injuries, the differences between flying in the day and night environment from an ergonomic perspective, specifics related to the helmet loads and masses currently employed by helicopter aircrew, and the benefits offered by physical training to optimize fitness and increase the physiologic work capacity.

METHODOLOGY

A comprehensive search of the relevant literature was conducted as it related to neck injuries and neck pain in military helicopter personnel. Searches were performed using PubMed, OVID, Web of Science, Google Scholar, and the Cochrane Library databases. The following criteria were used to search these databases:

1. Access to full text articles, reports, books, and book chapters in English;
2. Inclusion of the terms "neck pain" or "neck injury" with at least one of the following: "helicopter", "aircrew", "pilot", "night vision goggle", and "military"; and
3. Publication between the years 1975 and 2014.

The bibliography of each publication was reviewed to identify any relevant sources that were not identified using the primary search strategies indicated.

SPINAL ANATOMY

The spinal column consists of 26 bones that articulate in more than 30 joints to form a curved and flexible structure that protects the spinal cord, supports the axial skeleton, transfers the load of the trunk to the lower limbs, connects the thorax's musculoskeletal structures, and, perhaps most importantly, provides the base of support for the skull.[3,21,69] The head support allows the body's command and control center, the brain, to observe its environment and the use of NVG enhances this functional requirement under low-light conditions.

The cervical spine is composed of seven bones that are the smallest and most delicate of the spinal column.[69] The structure of the bones of the cervical spine and the locations of the muscles associated with the cervical spine are responsible for the significant amount of head movement, including flexion, extension, rotation, and combinations of flexion or extension with rotation. However, this delicacy also makes the cervical spine a fragile region when large forces are applied instantaneously (i.e., as a result of sudden impact in a motor vehicle accident or contact sports) or over an extended period of time (i.e., cumulative loading as seen in normal NVG flight over an aircrew member's career).

IMAGING RESULTS OF CERVICAL SPINE

Objective imaging findings of degenerative symptoms caused by repeated cervical and lumbar spine loading among pilots have been studied. Helicopter aircrew are the most likely fliers to have radiographic changes such as spondylitis, spondylarthritis, osteophytic spurring or arthrosis deformans in the cervical spine.[8,56] Landau et al.[64] used magnetic resonance imaging

(MRI) to assess the prevalence of lumbar and cervical degenerative changes in three subpopulations of pilots (fighter pilots, transport pilots, and helicopter pilots) who did not have a history of significant neck or back trauma. Cervical disc degeneration was found in 50% of the helicopter pilots, most commonly in the C5-C6 and C6-C7 joints. By comparison, 80% of transport pilots and 30% of fighter jet pilots had demonstrable cervical spine disease on MRI. As compared to the sample of transport pilots, the helicopter pilot sample had a greater severity of disc degeneration despite being, on average, 8 yr younger.[64] Disc degeneration was assessed on a scale of posterior herniation where the helicopter pilots averaged a grade of 3.0, while the transport pilots averaged a grade 2.6. Caution should be used when interpreting these results as MRI findings are poorly associated with severity of back and neck pain symptoms in the general population[98] and, for the purpose of this review, that caveat will shift the focus back to neuromuscular causes and solutions of neck pain among the helicopter community.

Estimates suggest the maximum tolerance of the structures of the cervical spine for single exposure to compressive forces without risk of injury is 2414 N for individuals 20 to 40 yr of age and 1738 N for individuals over the age of 40.[57] While normal military helicopter flight will not exceed those values, the same study estimates that prolonged muscle loads should not exceed 1% of an individual's maximal voluntary contraction (MVC). However, the helmet alone in neutral posture can result in an 18–28% increase in muscular activity in the neck as assessed with EMG prior to the addition of NVG or exposure to $+G_z$ forces.[87] The difficulty with interpreting these values as they relate to helicopter aircrew is the complexity of the job and the mobility it demands. Helicopter aircrew do not maintain a static neutral position while in flight and, as demonstrated mathematically by Hidalgo et al.,[57] small changes in cervical posture can result in large increases in the forces placed upon the ligaments, bone, intervertebral discs, and muscles. Forde et al.[32] demonstrated the increased cumulative load to be more pronounced over the duration of a simulated mission when the neck must support an NVG-equipped flight helmet as compared to the helmet alone.

NECK PAIN DEFINITIONS AND INJURY HYPOTHESES

A commonly agreed upon definition of neck pain is difficult to obtain. When the pain is muscular in nature, the term neck myalgia is often used and neck myalgia is a component of the category of injuries referred to as upper extremity muscle disorders (UEMD).[67,99] Visser and Dieën's[100] definition of UEMD as "disorders of muscle tissue proper, excluding tendon disorders and disorders of the tendinous insertions" with injuries characterized by subjective symptoms such as sensation of constant muscle fatigue, muscle stiffness, and radiating pain may be too limiting due to its exclusion of tendinous injuries. Further difficulties in defining neck pain consistently relates to the mechanism of injury; the forces and duration of application of these forces can vary greatly between overuse or cumulative load injuries and single exposure high impulse load injuries (e.g., what is often seen in fast-jet aircrew exposed to $> +4\ G_z$) are difficult to compare to cumulative loading injuries (e.g., helicopter aircrew exposed to low $+G_z$ and helmets with increased mass).

Neck pain research indicates pain and dysfunction to be multifactorial. External psychosocial factors, physical loading factors, and the psychological and biological characteristics of the individual are important[13,70,72] in addition to internal factors such as muscle degeneration and/or impaired neuromuscular function resulting from chronic overuse.[22,23] Posture, low $+G_z$ forces while using NVG, vibration while using NVG, and the overall weight and weight distribution of the helmet are reported as perceived causes of neck pain among aircrew.[95,96,106] A link between sex and neck pain has been suggested, with a decreased tolerance of certain helmet mounted loads [i.e., aft-loaded helmets such as the case would be with the use of NVG with a counterweight (NVGcw)] among female aircrew[9] and an increased incidence of neck pain as compared to their male colleagues.[95] Other studies have not supported this finding but cannot refute them due to a male predominance among research participants.[51]

With a poor correlation between radiographic findings and neck pain, applicable theories should focus on cervical soft tissue structures. Panjabi[74] presents a clear and logical multifactorial hypothesis for neck pain that incorporates the soft tissue structures. The proposed mechanism is cumulative microtrauma to the ligamentous structures as a result of an extended period of submaximal loading that results in impaired muscle function, including "muscle coordination and individual muscle force characteristics, i.e. onset, magnitude, and shut-off".[74] Other proposed mechanisms for injury in the literature include the "Cinderella hypothesis"[61,85,89] or the "nitric oxide/oxygen ration" hypothesis.[30] These similar hypotheses propose that sustained submaximal muscular contractions, particularly in the trapezius muscles, result in occlusion of capillaries and arterioles within the muscle. The occlusion severity is more pronounced as a result of physiological vasoconstriction in the setting of stress (including sustained periods of mental alertness) or as a result of head-forward posture.[30,89] As will be presented in a later section, decreased muscular perfusion and oxygenation also occurs as a result of whole body vibration (WBV).[68] Oxygen delivery and aerobic respiration at the cellular level is not possible in the heterogeneously occluded regions of the muscle and is measurable through a shift in the red-ox state of cytochrome-c oxidase (CtOx), the final enzyme in the electron transport chain. These shifts in the CtOx state are documented in the trapezius muscles of helicopter pilots flying a simulator.[50] Eriksen[30] states the "most effective non-pharmocological measure may be to reduce exposure to prolonged head-down neck flexed positions and psychosocial stress at work" in order to address localized ischemia contributing to neck pain.

Specific to helicopter aircrew, research strongly suggests a significant muscular component to the cervical injuries associated with NVG-use.[31,46,80] Using near infrared spectroscopy (NIRS), muscle perfusion to the trapezius muscles increased during simulated NVG missions as compared to day missions[47] that occurred regardless of cockpit seat side.[49] While this may seem to contradict the "nitric oxide/oxygen ration" hypothesis, Eriksen[30] states even small regions of occlusion, perhaps not appreciable by NIRS evaluation, may be sufficient to cause frequent exacerbations of neck pain. In support of the hypotheses identifying heterogeneous occlusion and hypoxia as a cause of myalgia, an acute decrease in the concentration of CtOx was observed during simulated NVG missions while an increase was observed to occur during day missions.[50] Forde et al.[32] found an increase in time spent in a flexed or head-down posture during simulated NVG missions as compared to day missions. To further support the muscular component of neck strain, Salmon et al.[81] reported increased cervical muscle strength and endurance as a result of a 12-wk training program with decreased self-reports of pain. The specific benefits offered by physical training will be discussed in greater detail in a later section.

DAY AND NIGHT WORKING ENVIRONMENTS

The working environment of helicopter aircrew has been the subject of much scrutiny due to the long-documented issue of LBP among this population.[34,35,44] Posture, pilot height, and vibration are the most often cited concerns for increased risk of low back pain. A helicopter pilot's posture has been linked to physiological findings of increased spinal muscle activity or fatigue during simulated[79] and actual[66] flight. The in-flight cervical spinal posture of helicopter pilots is described as flexed and axially rotated due to the location of particular flight controls.[28,66,75] Specifically, this posture allows the pilot to operate the collective control, responsible for the pitch of the rotor blades, which is located to the left and below the pilot's seat.

The majority of the available literature related to neck pain has focused primarily on fast-jet aircrew[41–44] with a more recent shift toward the inclusion of helicopter aircrew.[31,46,90] Substantial differences exist between the working environments of fast-jet and helicopter aircrew and these differences influence both the mechanism of injury and the subsequent methods of mitigation. Fast-jet operations may expose aircrew to maximal forces between +4.0 G_z and +7.0 G_z while helicopter aircrew rarely exceed +2.0 G_z.[42,71,104] The helmets of fast-jet aircrew range in mass from 1.31 kg – 2.15 kg[41,43] while a CF helicopter flight helmet, when equipped with NVGcw, may have a mass of 3.7 kg.[104] In fast-jet aircrew, the mean muscular strain, as indicated by percentage of a maximal voluntary contraction (MVC), has been reported to fall between 5–20% MVC during most missions.[71] Hamalaien[41] suggests the mass of the helmet alone necessitates a counter-moment that is comparable to 15% MVC to maintain a neutral head position. Under high +G_z exposure, the in-flight peak muscular strain of cervical neck flexors reportedly ranges from 40–80% of MVC, with the highest recorded value of in-flight strain being 257% of preflight MVC under standard conditions.[38,71] In fact, the recorded peak strain during in-flight maneuvers for all cervical muscle groups exceeded 100% of the preflight MVC on at least one occasion during flight maneuvers.[71] As a result of these factors, fast-jet aircrew can often identify the specific moment at which their injury occurred.

In helicopter aircrew, previous studies have identified increased G-force exposure, accumulated flying hours, head position, vibration, body posture, airframe and cockpit ergonomics, and head supported device use as the most common causative factors of neck pain while overall physical fitness is described as protective.[4,94,106] All of these factors are similar to the factors associated with low back pain among helicopter aircrew.[88] In helicopter aircrew, the weight of the helmet alone can cause an 18% and 28% increase in muscular activity in the sternocleidomastoid and cervical erector spinae muscles, respectively, as compared to resting conditions; with NVG, this increase becomes 29% and 34% for the sternocleidomastoid and cervical erector spinae, respectively.[87] Thus for helicopter aircrew, the injury is often more insidious as result of chronic exposure to forces countered by submaximal muscular contractions.

In a recent study with helicopter aircrew, only two variables are required to accurately predict risk of neck pain: the height of the crewmember and the length in hours of their longest NVG mission.[52] This is consistent with a recent U.S. Army study in which aircrew members at anthropometric extremes for body mass, neck circumference, leg length and height were at an increased risk of both back and neck pain.[102] To further support the argument that a link exists between low back and neck pain in this population, height was recently identified as the most important predictor of back pain among United States Navy helicopter aircrew.[73] Specifically, for every 1 inch (2.5 cm) in additional height above 71 inches (180 cm), the individual is 9.3% more likely to experience low back pain. The authors suggest these "taller pilots are more at risk for significant LBP due to greater need to 'hunch over' during flight…"[73]

In addition to the increased helmet mass, NVG do have another limitation. While they do provide optical clarity during low-light conditions, they do so through a much smaller field of view. Normally, the human eyes provide a field of view of approximately 200° horizontally and 135° vertically.[105] NVG can reduce that field of view to approximately 40° both horizontally and vertically.[26,37] As a result, the aircrew member cannot rely on peripheral vision at night in the same manner as they can during the day. They must move their head and neck to a greater extent in order to bring objects of interest directly into this limited field of view. The C7/T1 joint serves as the point of origin for moment calculation of neck flexion, extension, and rotational postures, where the head's center of gravity is assumed at the ear canal.[32] The additional anterior mass of the NVG shifts the center of gravity forward and up, thus increasing the distance of the perpendicular moment arm while also requiring an increased muscular force to compensate for its weight moment.[87] Forde et al.[32] demonstrated that this resulted in increased mobility and changes in posture that, when combined with the increased mass of the helmet with NVG or NVGcw, resulted in increased moments, peak loads, cumulative loads, and shear forces as compared to simulated day missions.

Another constant in the environment of helicopter aircrew is vibration, with one source describing helicopters as "thousands of parts vibrating in close formation".[109] In the case of helicopter flight, the vibration is a result of the main rotors. The amplitude and/or frequency of the vibration from the rotors can be increased operationally (flight speed, in-flight maneuvers, environmental conditions, and altitude) but the transmitted vibration spectrum can only be decreased by careful aircraft and seat design.[55] Whole body vibration (WBV) transmitted to the entire body through the seat of moving vehicles is linked to performance decrements such as fatigue, and to medical problems such as chronic pain, degenerative disease in the spinal column, and damage to the peripheral nervous system.[55,68,84] Similar to the previously presented hypotheses linking low-level muscular contractions of the trapezius during head-forward posture and decreased muscle perfusion,[30,89] Maikala and Bhambhani[68] report WBV can cause acute changes in blood volume, perfusion, and oxygenation in a working muscle.

Currently, the unmodified helicopter cockpit seat only suppresses 6–15% of vibration transmission.[58] It has been reported that 4.5–5.5 Hz is the frequency range at which the maximum WBV energy transfer to the human spine occurs[68] and recent work in a helicopter and seat identical to what is employed by the CF's tactical helicopter squadrons indicates this range to be one of the principal harmonics of the aircraft's vibration spectrum.[18,19] As a result, the magnitude of vibration experienced by pilots at the head and neck is roughly double that of the magnitude of vibration experienced at the lower back.[18,19] This correlates with earlier findings that posture and helmet load positively influences seat-to-head vibration transmissibility and muscle activity.[90,91] Therefore it is reasonable to hypothesize the vibration profile of the CH-146 in the setting of an unbalanced helmet load such as with NVG could be synergistic in their contribution to the rates of neck pain reported by helicopter aircrew. Chen et al.[19] report an adaptive seat cushion prototype effectively suppressed vibration in the range of approximately 5 Hz while the use of a magneto-rheological seat suspension system suppressed vertical vibration transmission by 76% on a 50th percentile male helicopter pilot.[58] This finding indicates that modified seats may be an effective countermeasure to mitigate vibration transmission to reduce the risk of negative health outcomes.

HELMETS, MASSES, AND LOADS

Typical flight helmets weigh approximately 1.5 kg.[12] More specifically, a CF helicopter flight helmet has a mass of 1.4 kg while a CF helmet equipped with NVGcw has a mass of approximately 3.7 kg.[104] NVGcw represents an additional mass of 0.05–0.4 kg as compared to NVG alone.[96,104] NVGcw are demonstrated to have a beneficial effect on decreasing the metabolic activity of the trapezius muscles during simulated missions[48] and the NVGcw mass results in the smaller neck muscles, such as the sternocleidomastoid and splenius capitis, experiencing increased muscular activity, as assessed by electromyography (EMG), in a laboratory setting with dynamic postures designed to simulate in-flight tasks with NVG and NVGcw.[51] Using static biomechanical analysis, Thuresson et al.[92] found the moment-reducing effect from NVGcw increased in the neutral position as compared to NVG. But, in a flexed non-neutral posture, the moment reducing effect of NVGcw is not apparent. This supports an inverse relationship between neck flexion and NVGcw based relief; NVGcw provide less relief as the neck is increasingly flexed.[45] Improved helmet fit and balance alone are reported to be enough to decrease the subjective discomfort reported by helicopter aircrew even in the setting of an unbalanced load with respect the head's anatomical center of gravity.[96]

The center of mass of a flight helmet typically resides forward and superior to the natural pivot point of the neck.[15,32,87] This results in a constant moment acting on the muscles of the neck, in particular the extensor groups, when the head is in neutral position. Butler and Alem[16] suggest an upper limit for helmet torque of 90 N • cm^{-1} during long duration helicopter flight (> 4 h) in male subjects to limit the biomechanical stress on the cervical structures; Barazanji and Alem[9] confirmed this upper limit for women during static laboratory testing with different helmet configurations. However, as Butler[15] illustrates and as Forde et al.[32] quantifies, very little time is spent in flight in a neutral posture while wearing either a helmet or NVG. Forde et al.[32] identified the location of the centers of mass of the various different configurations of the CF helicopter flight helmet – helmet alone vs. helmet with NVG vs. helmet with NVGcw – and reported slightly different results than Butler.[15] Forde et al.[32] suggest the helmet-only configuration results in a center of mass that is superior and posterior to the center of mass of the head. However, the other configurations, NVG and NVGcw, still remain forward and superior (**Fig. 1**), as reported by others.[15,45,87] This alteration in the center of mass has quantifiable effects during head movements to bring the field of view below the horizon.[53]

Sovelius et al.[87] suggest lowering the center of gravity of a helmet's weight has a more significant impact on relieving

Fig. 1. The centers of mass of the various helmet configurations used by helicopter aircrew: A) the head, alone; B) the helmet alone; C) NVG; D) NVGcw. From Forde et al. (28); reproduced with permission from the authors.

cervical muscle loading than decreasing the weight of the NVG systems currently in use. This is consistent with pioneering work in the realm of helmet masses, centers of gravity, and neck muscle fatigue; however, it would seem this knowledge that a "forward and high" configuration is the least desirable configuration has not been applied despite being available for 30 yr.[76] Philips and Petrofsky[76] used loads comparable to the current NVG and NVGcw systems to suggest that if a balanced helmet load could not be achieved, it was more desirable to have a load that was "forward and low," "aftward and low," or "right lateral and low," as compared to "center and high." The benefit of a more centered load in relation to the occiput and atlantio-axial joint extends beyond just comfort while performing regular flight duties. In the extreme circumstances during which loading may be instantaneously increased (i.e., during impact in a crash scenario), Ashrafiuon et al.[6] used manikin models to illustrate the increased emergency safety associated with a load with a lower center of gravity specific to helicopter flight helmets and NVG equipment. Brozoski et al.[14] similarly demonstrated decreased tolerance for deviation from the natural center of gravity of the head as the helmet mass increased during simulated impacts.

More recent work does not fully support the inclusion of a lateral imbalance favoring increased loading on the right side. Isometric testing has demonstrated a decreased strength and endurance capacity of the right-sided cervical muscles as compared to the left in a helicopter aircrew population.[50,51] Further, when monitoring muscle metabolism with NIRS during simulated missions, results indicated increased muscle metabolism in the musculature on the right side of the cervical spine,[47] regardless of cockpit seat side.[49] In additional work on the lumbar region, authors have noted increased EMG activity in the musculature on the right side of the lumbar spinal column[66] and sources hypothesize the left-leaning in-flight posture demanded by the operation of the collective and cyclic controls contributes to this phenomenon.[75,79] Regardless, despite the use of NVGcw in an effort to move the center of mass toward a more natural location, it remains forward and high as compared to the natural anatomy.[32]

The addition of mass to a flight helmet does not automatically result in a balanced load. Gallagher et al.,[36] in a laboratory setting with 4 kg and 6 kg helmets, reported that aircrew preferred to wear a heavier but balanced helmet for a prolonged period of time as compared to a lighter helmet with centers of gravity similar to the current helicopter helmet models. Most recently, Van de Oord et al.[95,96] demonstrated that custom work to optimize the fit of the helmet to the individual crewmember can reduce neck pain and discomfort despite an unbalanced operational load. This suggests helmet balance and helmet fit contribute significantly to the development or prevention of neck pain among aircrew members. Research with United States Army helicopter aircrew reported helmet size did not correlate with head circumference.[102] This strongly suggests there is room for improvement in optimizing helmet fit to enhance balance and decrease neck strain. It would seem prudent and cost effective for future work to prioritize the development of a more balanced helmet with customizable fit rather than focusing solely on a lighter helmet and NVG system.

BENEFITS OF PHYSICAL FITNESS AND TRAINING ON AIRCREW WORK CAPACITY

In the general population with chronic neck pain, the addition of exercise to the treatment regimen is beneficial in both the short-term[13,20,40] and the long-term.[40,107,108] In flight-related neck pain, a recent shift toward physical fitness and training has occurred to provide "better muscle conditioning…, enhanced muscle coordination, and head support strategies…to prevent neck injuries stemming from the extra mass of the helmet".[87] Research to evaluate the associated factors of flight-related neck pain in British aircrew suggest aerobic exercise, weight training, and neck strength training were all preventative in their relationship with neck pain.[106] Van den Oord et al.[93] measured differences in neck muscle strength and cervical range of motion between aircrew with and without neck pain. These results indicated those without pain trend toward greater, nonsignificant, strength and cervical range of motion as compared to their symptomatic colleagues.

In fast-jet aircrew, increased neck muscle strength is suggested to protect and stabilize the head and neck muscles during brief episodes of increased loading as a result of $+G_z$[3] while other studies suggest it is the cumulative $+G_z$ loading rather than the peak $+G_z$ load that is a better predictor of neck pain.[60] The ideology behind the link in strength and injury is functionally stronger neck muscles will be able to maintain the head in a neutral position to overcome the gravitational accelerations. However, in helicopter aircrew, the link between decreased neck strength in terms of a maximal voluntary contraction and injury is not supported by the literature;[3,51,94] one study reports increased "physical fatigue" at the end of NVG flight duties among aircrew with neck pain as compared to their pain-free colleagues.[94] This is supported by work with EMG in which differences were observed between the normalized median frequency of neck muscles in either flexion[3] or extension[54] in helicopter aircrew with and without pain; those with pain tended to have a blunted EMG signal as compared to their healthy colleagues. Ang et al.[5] provide evidence that specific training of the neck musculature can improve the work capacity of those muscles as assessed by EMG and decrease reports of pain among helicopter aircrew. Thus, the hypothesis specific to helicopter aircrew suggests training programs focus on muscular endurance and general fitness to limit the effects of cumulative exposure to the multiple factors that contribute to neck pain as opposed to programs intending to increase strength.[51,82,106]

After Wickes et al.[106] suggested a protective link between regular physical exercise, in this case aerobic fitness in the form of participation in a self-selected activity (e.g., jogging, soccer, racquet sports), researchers have tested either the relationship between neck muscle function or the efficacy of neck strengthening programs on reported pain. Sovelius et al.[87] note it is the sternocleidomastoid that demonstrated increased EMG activity in order to maintain a neutral posture in response to the additional load of either a flight helmet or a flight helmet with NVG. Harrison et al.[51] report the smaller muscles of the neck (i.e., sternocleidomastoid and splenius capitis) are more prone to fatigue during submaximal endurance testing as compared to the larger muscle groups (i.e., the mid and lower trapezius) while seated in a cockpit chair. Ang et al.[5] found a supervised exercise regimen, specifically focused on neck and shoulder exercises, significantly reduced rates of neck injury in a 1-yr follow-up. Additionally, this benefit is possible with as little as 1 h per week for 6 wk dedicated to performing the specific exercises. With respect to addressing the neuromuscular component of training specificity, Sovelius et al.[87] suggest a benefit from the use of head loading and trampoline training. While simulating changes in $+G_z$ loading (approximately 0–4 $+G_z$), the trampoline also provides a means by which to introduce low-level repetitive loading to aircrew training programs.

Salmon et al.[81] randomly distributed a group of helicopter aircrew for a 12-wk intervention as participants in either an endurance-training program (ETP) or a coordination-training program (CTP). The ETP group performed dynamic movements with resistance designed to equal 30% of each participant's baseline MVC while the CTP participants performed low load isometric exercises focused on the deep cervical stabilizer muscles. Compared to control subjects, both ETP and CTP groups resulted in significantly reduced subjective neck pain, and additionally, increased MVC and muscular endurance. These results further suggest that neck-specific exercise programs, like improved helmet fit, can reduce neck pain in an efficient and inexpensive manner.

RECOMMENDATIONS

The factors that contribute to the occurrence of neck pain among helicopter aircrew are multifactorial. Helmet mass, the distribution and balance of the helmet mass, the number of flight hours logged with NVG, the use of NVGcw, the height of the crewmember, the vibration of the helicopter, the in-flight posture required to perform essential duties, the overall fitness of the crewmember, and the neck/shoulder specific fitness of the crewmember are just some of the examples of factors identified in the literature as being contributory. The question now is what can be done about these factors?

The focus of future research should address all of these issues as it is highly unlikely that any one of them, alone, will be sufficient to reduce the incidence of neck pain among helicopter aircrew. Ergonomists and industry should make a conscious effort to design equipment that has a lower center of gravity as suggested by research, the earliest of which is 30 yr old.[77,87] As has already started, industry and research should continue to design new seats that meet the safety requirements for military flight while reducing vibration transmission to the crewmember.[19,58]

Future ergonomic and biomechanical work should quantify the duration of time, in flight, that each crewmember spends in specific postures and make certain each crewmember has a customized helmet fit performed. Head forward flexion is linked to reports of neck pain and discomfort in the general population,[30,89] but other than what is reported by Weirstra[104] and Forde et al., [32] little is known about the in-flight tasks and postures of helicopter crewmembers, particularly flight engineers. Obtaining this information would likely dictate changes to the unregulated manner in which aircrew choose to use NVGcw based on personal preference. Better fitting helmets will also likely help to decrease neck pain and irritation during night flights.[96] Beyond the optimized fit, perhaps not every crewmember has an in-flight posture and loading profile that warrants the use of NVGcw.

Lastly, fitness is an obvious solution that often appears to be overlooked. In the helicopter community, encouragement of a structured fitness program that regularly includes either aerobic fitness[106] or neck-specific exercises to address muscular endurance and posture[5,81,82] is the most likely to provide nearly immediate improvements in the current neck pain situation in the helicopter community.[1]

CONCLUSIONS

The issue of neck pain as a result of military helicopter operations persists. Numerous research projects are publishing results that consistently highlight the same areas of concerns[4,46,90] as have been highlighted by this review. The underlying commonality among the factors is the need for a kinesiological approach that incorporates both a human-factors engineering perspective as well as a focus on the neuromuscular and hemodynamic physiology in order to fully address the issues.

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