Military pilots and rear aircrew members are occupations with several occupational exposures that might cause neck pain. In addition to the negative impact of neck pain on health, safety is one of the main concerns for the military aviation, because neck pain may interfere with flying performance. It might be obvious that flight-related neck pain should be prevented whenever possible.

The main objective of this thesis was to study neck pain in military aircrew especially of the Royal Netherlands Air Force and, in doing so, to generate knowledge about the extent of the problem, to identify associated factors concerning the aircrew’s capacity and work situation, and to learn about aircrew’s experiences to find and test feasible preventive measures. A renewed protocol to optimise aircrew’s helmet fit was tested and evaluated on the experienced neck load and neck pain during night flights. Recommendations for research, practice and industry are given.

Marieke van den Oord studied human movement sciences and ergonomics at the VU University in Amsterdam. She works as a researcher in human factors in military aviation at the Center for Man in Aviation of the Royal Netherlands Air Force. For her scientific research projects that resulted in the present thesis she has collaborated with the Coronel Institute for Occupational Health, Academic Medical Center, University of Amsterdam.
Prevention of flight-related neck pain in military aircrew

Marieke H.A.H. van den Oord
The research described in this thesis was carried out at the Academic Medical Center, University of Amsterdam, department: Coronel Institute of Occupational Health, the Netherlands, supported by the Center for Man in Aviation of the Royal Netherlands Air Force.
Prevention of flight-related neck pain in military aircrew

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Faculteit der Geneeskunde
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Prevention of flight-related neck pain in military aircrew
General Introduction
Chapter 1
Prevention of flight-related neck pain in military aircrew
Work-related neck pain

Along with back pain, neck pain is one of the most common musculoskeletal complaints. In this thesis, neck complaints are considered as a musculoskeletal disorder, with pain as the most important symptom.

Musculoskeletal disorders (MSDs) are injuries or dysfunctions affecting muscles, tendons, and supporting structures of the body [31]. They include sprains, strains, tears, soreness, discomfort and pain of these structures. Work-related MSDs (WMSDs) are defined by the World Health Organisation as disorders that result from a number of factors and where the work environment and the performance of the work contribute significantly, but vary in magnitude, to the causation of the disease [32]. Work-related musculoskeletal complaints have become a major concern for employees, employers and governments because of their negative impact on the health and productivity of the employees [11]. Moreover, WMSD is the most expensive form of work disability [21].

It is generally agreed that the aetiology of neck pain in the working population is multifactorial and complex and involves individual, physical and psychosocial factors [3;9]. Several studies have suggested a relationship between certain occupational exposures and neck pain [9] where the physical and psychosocial loads seem to make important contributions to neck pain and work absence due to neck pain [2;3]. Several specific occupations have been associated with the risk of neck pain [9].

Military pilots and rear aircrew members have specific occupations with several occupational exposures that can be attributed as risk factors for neck pain as explained in this chapter. In addition to the previously mentioned negative impact of WMSDs on health and the expense due to work disability, safety is one of the main concerns for the military aviation. Neck pain may interfere with flying performance [22] and should therefore be prevented whenever possible.

Towards prevention

It might be obvious that it is important for both employees as well as employers to prevent work-related neck pain. Before proposing an intervention that might be effective in preventing or alleviating work-related musculoskeletal complaints, it is important to gain insight into the relationship between work and these musculoskeletal complaints. Many conceptual models can be found in the scientific literature that describes the process in which the work situation evokes responses in the human organism. Van Dijk et al. [26] described in 1990 in their dynamic model of workload the way in which a worker’s capacity influences the work load, its consequences and vice versa (see also [10;15;28]). Armstrong et al. [4] presented in 1993 a dose-response model that showed the iterative process between a sequence of different responses and their interactions with the worker’s capacity. Westgaard and Winkel [30] described in 1997 in their model the path for ergonomic interventions to influence musculoskeletal health. The
conceptual model “ergonomic interventions and work-related health” (Figure 1) is developed by combining these different models. In this thesis, the presented model is used as a framework for the description of the basic concepts of the model within the occupational population of the military aircrew and to explain the steps taken in this thesis towards the prevention of flight-related neck pain.

The main sets of interacting concepts in the model explaining work-related neck pain are exposure, dose, response, and capacity. These concepts are explained in Table I. Ergonomic interventions can act on the worker’s capacity, on several aspects related to the exposure, and on the interaction between the worker’s capacity and the external exposure. Concerning the exposure, the work situation involves the work demands with the task autonomy for the worker. The work demands are the tasks to be performed, including the tools and (personal protective) equipment, such as a flight helmet in the case of military aircrew, the work environment and the work conditions. The task autonomy involves the timing and method control, which a worker may or may not have in the work situation [27]. How the work is performed and the actual working method are determined by the interaction between the demands of the work situation and the worker’s capacity, such as physical skills learned by experience. The interaction between the actual working method and the worker’s capacity, such as body dimensions, leads to (constrained) postures and specific movements of the worker and the exertion of forces. For example, the posture of a pilot adopted when operating a helicopter is determined by the tasks the pilot has to perform in the cockpit, the shape of the cockpit seat, the settings of the seat chosen by the pilot and the pilot’s body dimensions. The work situation, the actual working method and the posture/movement/exerted forces are considered to be external exposures, and the individual capacity of the worker can modify this external exposure. This external exposure produces a certain dose or internal exposure depending on the interaction with the worker’s capacity. Internal exposure refers to the moments and forces within the human body. This internal exposure leads to acute responses in the worker at the system, organ, cellular and molecular levels (e.g., changes in heart rate, breathing frequency, muscle activity and substrate concentration). These acute responses are temporary short-term effects, and depending on the frequency and duration of the internal exposure and the worker’s capacity, include the development of fatigue, discomfort or pain. These short-term effects represent the workload during work and for some hours thereafter. In the case of insufficient recovery, these short-term effects can act on a longer time-scale and lead to more permanent effects, such as musculoskeletal complaints or chronic fatigue. These negative long-term health effects can worsen the worker’s capacity. However, in the case of sufficient recovery, a certain workload can lead to positive long-term health effects, such as improvements of skills or physical condition, resulting in positive changes in the worker’s capacity. The work capacity of a worker occupies a prominent place in the model because of its interactions with the three concepts of exposure,
dose and response. The work capacity depends on the physical, cognitive, and mental characteristics and capacities of a worker [10].

To prevent work causing negative long-term health effects such as musculoskeletal complaints, ergonomic interventions might be proposed that target the worker’s capacity, the external exposure or the interaction between the two. For instance, by increasing a worker’s physical capacity through worker job-specific physical training, the workload will be relatively reduced; by training in work methods, such as lifting techniques, the actual working method might be changed; by providing the worker advanced equipment, the work demands change and the absolute workload might be reduced. Before introducing ergonomic interventions, it is important to know what factors of the worker’s capacity and the external exposure are associated with the musculoskeletal complaints, which is specific to this thesis regarding neck pain, so the ergonomic interventions can target to these specific factors.

In the next paragraph, the work of military aircrew using the concepts of the presented conceptual model is described.

**The work exposures of military aircrew**

The main tasks of military aircrew are preparing, executing and evaluating flight missions. These tasks are executed in training situations and in the real operational theatre, worldwide and during all possible threat levels. The Royal Netherlands Air Force (RNLAF) delivers air power by different types of aircrafts each with their specific operational tasks.

This thesis is about pilots operating the F-16 fast jet fighter plane (photo 1-3), about helicopter pilots (photo 4-6) and about rear aircrew members who work in the cabin of the helicopter (photo 7-9).
Figure 1. Conceptual model that gives insight into the work-relatedness of musculoskeletal complaints and where to intervene with ergonomic measures. (Based on: van Dijk et al. [26], Armstrong et al. [4], and Westgaard and Winkel [30])
Table I. Definitions of the concepts used in the conceptual model presented in Figure 1.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td><strong>EXPOSURE</strong></td>
<td></td>
</tr>
<tr>
<td>Work situation</td>
<td>The work demands and the task autonomy. The work demands are the tasks to be performed, including the tools and (personal protective) equipment, the work environment and the work conditions. The task autonomy involves the timing and method control which a worker may or may not have in the work situation [27].</td>
</tr>
<tr>
<td>Actual working method</td>
<td>The way the work is performed, characterised by, for example work rate, utilisation of devices, lifting techniques, and number of breaks [10].</td>
</tr>
<tr>
<td>Posture, movement and exerted forces</td>
<td>The sequence of body postures, movements and exerted forces on the environment during work [10].</td>
</tr>
<tr>
<td><strong>DOSE</strong></td>
<td></td>
</tr>
<tr>
<td>Internal exposure</td>
<td>Moments and forces within the human body; passive structures of the musculoskeletal system are exposed to internal forces along and moments around each of the three axes. With respect to active structures, recruitment patterns of muscles are generated to counterbalance net moments on motion segments caused by gravity, other external forces, and inertial forces [25].</td>
</tr>
<tr>
<td><strong>RESPONSE</strong></td>
<td></td>
</tr>
<tr>
<td>Short-term effects</td>
<td>All temporary physical and mental responses to the internal exposure, such as changes in breathing frequency, feelings of fatigue, discomfort and pain during work and for some hours thereafter [15].</td>
</tr>
<tr>
<td>Long-term effects</td>
<td>All recurrent or permanent effects of workload on health, both positive and negative [10].</td>
</tr>
<tr>
<td><strong>CAPACITY</strong></td>
<td></td>
</tr>
<tr>
<td>Worker’s capacity</td>
<td>The physical, cognitive and mental characteristics of a worker. Examples are body dimensions, strength, expertise, age and gender. Although some characteristics are non-modifiable such as height, the worker’s capacity is a dynamic measure. Changes may occur in a short-term period, such as changes over the day caused by fatigue, as well as in long-term periods, such as increase or decrease in muscle strength in months or years [10].</td>
</tr>
<tr>
<td><strong>ERGO NO M IC INTERVENTION</strong></td>
<td>A change process initiated and implemented by a stakeholder with the aim of introducing measures that influence occupational mechanical exposures and/or acute responses in order to promote musculoskeletal health [30].</td>
</tr>
</tbody>
</table>
During real flight, the F-16 pilot is subjected to high sustaining acceleration and deceleration forces. These forces are expressed in G-forces. One G corresponds to 9.81 m/sec². The F-16 fighter plane is capable of accelerations up to 9 Gs, and this performance capacity exceeds the human physiological tolerance. While additional equipment such as an anti-gravity suit is needed to counter the effects of the high Gs such as loss of vision and unconsciousness, the musculoskeletal system simply has to deal with these high demands. When a pilot is pulling 9 Gs, it means that the apparent body weight of a pilot is 9 times the pilot’s actual weight. In addition, F-16 pilots use head-mounted equipment such as helmets, oxygen masks and night vision goggles (NVG), which create extra weight on the pilot’s neck. This equipment can result in loads up to 65kg while flying at 9 Gs [8;13]. In addition to extra weight, the helmet and mounted equipment bring the centre of gravity of the mass above the neck further up and forward, resulting in an increased flexing moment force [8;13]. For safety reasons, F-16 pilots are not allowed to use counterweights at the back of their helmets to reduce this moment of force. During flight, the F-16 pilot is locked in a harness, which means that the trunk is fixed to the seat and the only moving part of the spine is the neck. The neck can bear the most G-forces in a neutral position [8;14]. However, especially during aerial combat manoeuvring, fighter pilots need to maintain their situational awareness to be able to counteract the attacks of their adversaries, which involves manoeuvring their heads and necks to the sides and the rear [19]. The head position is further determined by the 30° reclined seat-back angle. This seat-back angle results in a higher physiological G-tolerance compared to an upright body position, but it also means that pilots need to flex their lower neck to a greater extent and extend their upper neck to a greater extent to maintain a normal direction of gaze in relationship to the horizontal plane [16].
Helicopter pilots and rear aircrew members

Several helicopter types are flown by the Defence Helicopter Command\(^1\) of the RNLAF and at the start of the research of this thesis in 2006, these types were the following: the ICH-47D Chinook, the AS-532 U2 Cougar, the Augusta-Bell 412, the Alouette III, the West-land SH-14D Lynx helicopter and the AH-64D Apache. Helicopter pilots and rear aircrew members perform different tasks in the helicopter. The pilots work in the cockpit and fly the helicopter that, depending on the type of helicopter and mission, is used to transport troops and cargo, perform search and rescue missions, and provide close combat support for ground troops. The rear aircrew members work in the cabin of the helicopter, and their main tasks include troop management, material handling, hoist operation, rescue, surveillance and clearance tasks, and sensor operation. The pilot manoeuvres the helicopter with feet and hands; the feet control the rudder pedals, the left hand controls the collective pitch lever that is situated at the left side of the pilot, and the right hand operates the cyclic stick that is situated between the pilot’s legs. This layout of the controls forces the pilot to sit in a slouched posture with a slight twist of the body to the left\(^{18;20}\). The rear aircrew members are less fixed in one position and their tasks require different body and head postures and movements, including sitting forward, kneeling, standing positions with the trunk flexed and rotated and the head out of the window, and lying positions with the head outside the hatch for hooking and hoisting tasks\(^{17}\). Both pilots and rear aircrew members wear flight helmets and mounted equipment such as night vision goggles and head up displays. As mentioned before, this head equipment alters the position of the centre of mass forward-upward\(^{13}\). Helicopter pilots are allowed to put counter-weights at the back of their helmets to reduce the moment force caused by the altered position of the centre of mass. However, while the counterweights may reduce the moment of force in upright head and neck positions, they increase the total weight of the headgear and may cause unexpected torque in non-neutral head positions\(^{24}\). The rotor blades above the cabin are typical for helicopters. They keep the helicopter in the air by pressing air downward to

\(^{1}\) The Defence Helicopter Command of the Royal Netherlands Air Force includes all land and sea tasked helicopter units of the Defence Organisation.
achieve lift. Each time a blade passes the cabin, it sustains a blow from the air pushed downwards, causing a shake and a whole-body vibration inside the helicopter. Research in laboratory settings has shown that head positions, head equipment and whole body vibrations are significant for neck load and seat-to-head transmissibility of vibrations [23].

**Military aircrew’s capacity**

Before aircrew candidates join the military and start flying school, they are medically, psychologically and physically checked and have to meet, depending on function and aircraft type, certain criteria. Different criteria for body dimensions exist for different types of aircraft. These criteria are primary based on body clearance within the cockpit. For example, the head with the helmet should not touch the canopy in the F-16 and Apache helicopter or the above control panels of the transport helicopters. Additionally, the legs should not touch the front panels, because free movement is necessary to control the rudder pedals, and in the F-16 clearance of the legs is also important in case of ejection. The cockpit of the F-16 and the helicopter is designed for a relatively stricter population when it comes to body dimensions in relation to ergonomically favourable (and comfortable) fits. This means an ergonomically unfavourable fit for many of the selected pilots. The physical screening involves strength tests of legs, arms and trunk and an anaerobic and aerobic capacity test. The medical examination includes an X-ray of the back, and the psychological screening includes motivational and mental capacity tests. The employer assumes that after the total screening the selected pilots and rear aircrew members are physically, medically and mentally in a fit-to-fly condition.

**Neck pain in military aircrew**

In 1988, the first reports of neck pain in fighter pilots were published in the scientific literature. Vanderbeek [29] reported a three-month prevalence of 51% in U.S. air force fighter pilots flying the F-5, F-15 and F-16, with higher prevalence of neck pain
reported in pilots flying the F-16, which is the higher G-capacity aircraft. The only high-G performance aircraft currently operated by The Royal Netherlands Air Force is the F-16. Prevalence rates of neck pain in F-16 pilots were also reported by Albano and Stanford [1]; one-year prevalence of neck pain was 57% and for a pilot’s whole career it was 85%.

At the start of the research of this thesis in 2006, studies concerning work-related musculoskeletal complaints in helicopter pilots reported mainly about back pain (e.g.,[5;6;12]). Only two survey studies, both focusing on back pain, reported data about the prevalence of neck pain. Thomae et al. [22] reported a one-year prevalence of any neck pain of 29% among Australian military helicopter pilots, and Bridger et al. [7] reported a one-year prevalence of 48% among British helicopter pilots.

**Rationale for this thesis**

Neck pain in fighter pilots has been studied in several epidemiological and experimental studies and is a recognised occupational problem in this population. At the start of the research of this thesis in 2006, neck pain in helicopter pilots and rear aircrew members was a less investigated topic, though several factors within their work situation had been suggested as risk factors [23]. For both F-16 pilots and helicopter aircrew, the question remains why some aircrew members develop neck pain and others do not. Referring to the conceptual model presented in Figure 1, it is important to identify the factors that characterise aircrew with and without neck pain. When it comes to the prevention of neck pain, solutions are often sought in improving aircrew’s capacity. Neck-strengthening exercises have been recommended to F-16 pilots [8], while other motor skills could also play an important role in the occurrence of neck pain. Furthermore, fewer attempts have been made in introducing ergonomic interventions targeted at the work exposure of the military aircrew and/or its interaction with the aircrew’s capacities. Consequently, little is known about the effects of such interventions on the aircrew’s responses and neck pain. Because of the operational demands and regulations that come with military flying, it is believed that interventions to lower the work exposures are not feasible. Therefore, the focus in preventing neck pain is necessarily on the individual. The experiences of the aircrew could provide important information in the development of interventions aimed at the prevention of neck pain.

**Thesis objectives and research questions**

The main objective of this thesis is to study neck pain in military aircrew especially of the Royal Netherlands Air Force and in doing so to generate knowledge about the extent of the problem, to identify associated factors concerning the aircrew’s capacity and work situation, and to learn about aircrew’s experiences to find and test feasible preventive measures.
The research questions are as follows:
1. What is the prevalence of flight-related neck pain in military aircrew?
2. What aspects of the aircrew members’ capacity and which work factors are associated with flight-related neck pain?
3. Can an optimised helmet fit reduce the neck load and pain during flight in helicopter aircrew?

**Thesis outline**

Parts of this thesis were performed in collaboration with the Belgian Defence, which also operates the F-16 fighter plane. After collecting and analysing the data to answer the first two research questions for the F-16 pilots, it was decided that the Belgian research group would further study neck pain in the F-16 pilots and the Dutch research group would study neck pain in the helicopter aircrew. As a result, this thesis contains the results on the first two research questions concerning both F-16 and helicopter aircrew members, and the third research question concerns solely the helicopter pilots and rear aircrew members. In Chapters 2, 4 and 5, the extent of flight-related neck pain is estimated in F-16 pilots, helicopter pilots and rear aircrew members, respectively (research question 1). In Chapters 2 and 4, work-related, individual, and health-related factors are compared between F-16 and helicopter pilots with regular and continuous neck pain and their colleagues without these complaints (research question 2). Chapter 5 addresses the exposures to postures, movements and exerted forces during work of helicopter pilots and rear aircrew members. Chapters 3 and 6 focus on the aircrew’s physical capacity of the neck (research question 2). The neck strength, range of motion and position sense are assessed and compared between F-16 pilots, helicopter pilots and rear aircrew with regular and continuous neck pain and their colleagues without these complaints. In Chapter 7 the experiences of the helicopter pilots are explored and factors related to the experienced neck load during flight are identified. In Chapter 8 the short-term responses of an optimised helmet fit during real flight are evaluated (research question 3). Finally, in Chapter 9, the main research findings are summarised and discussed and recommendations are presented.
References


Individual, work- and flight-related issues in F-16 pilots reporting neck pain

Chapter 2

Veerle De Loose, Marieke Van den Oord, Frédéric Burnotte, Damien Van Tiggelen, Veerle Stevens, Barbara Cagnie, Erik Witvrouw, Lieven Danneels

Aviation, Space, and Environmental Medicine 2008;79:779-783
Abstract

Introduction: Neck pain is a common problem in F-16 pilots. A cross-sectional survey was used to determine the self-reported one-year prevalence of neck pain and to compare individual, work-related, and flight-related characteristics in F-16 pilots with and without neck pain.

Methods: There were 90 male F-16 pilots of the Belgian Air Force and The Royal Netherlands Air Force who voluntarily completed an anonymous survey.

Results: The one-year prevalence of neck pain was 18.9%. Pilots were divided into two groups: a healthy (HG) and a neck pain group (NPG). This study could not identify individual or specific flight-related differences between these two groups. High force demands, often sitting for a long time, frequently holding the neck in a forward bent posture, and being physically tired were all physical work-related factors that were reported significantly more often in the NPG. The NPG also reported significantly more psychosocial factors, such as being mentally tired at the end of the day and being annoyed by others at the workplace.

Discussion: Since the specific flight-related factors were not significantly different between the HG and NPG, physical and psychosocial factors could have been important factors in the development or maintenance of neck pain in F-16 pilots.

Conclusion: The results of this study highlight for the first time that, in addition to flight-related issues, other aspects must be considered in analyzing neck pain. These other aspects stress the importance of a broader approach when considering neck pain, even in this population that is exposed to very high loads during flight.
Introduction

Neck pain is a well described problem among pilots flying high-performance aircrafts. The one-year prevalence of neck pain in fighter pilots is high, fluctuating between 50% and 89% [1;8]. In literature, neck pain prevalence in F-16 pilots varies between 50% and 63% [1;8;25]. These numbers are higher than in general populations, most likely due to the very dynamic environment which subjects the pilot’s cervical spine to high demands [1]. In the general population, the one-year prevalence of workers with neck pain ranged from 27.1 to 47.8% [13]. Many contributing factors have already been identified in the etiology of flight-related neck pain: number of flight hours, age, neck strength, G level, repeated exposure to high +Gz, head position and movements, sitting posture, 30° declination of the F-16 ejection seat (ACESS II), unexpected acceleration in backseat aircrew, and use of head-mounted devices (night vision goggles (NVG), helmet, oxygen mask) [2;12;15]. However, a pilot’s job also involves a number of other activities apart from flying: mission planning, briefings and debriefings, preparing materials, and administration. The nature of most of these activities is sharply in contrast with the demands of the flying assignment and requires standing and sitting postures for prolonged periods.

In the current study our aim was to determine the self-reported one-year prevalence of neck pain and to compare individual, flight- and work-related (physical and psychological) characteristics of F-16 pilots with and without neck pain. In addition, the current study sought to describe the nature of the neck pain experienced and to assess whether the pilots sought medical attention.

Methods

Subjects

The current study was a collaboration between The Belgian Air Force and The Royal Netherlands Air Force; both operate the F-16 Fighting Falcon. There were 90 male F-16 pilots who completed an anonymous survey voluntarily. The anonymity was guaranteed by using a code. A medical briefing introduced the study to the different squadrons. Later, a schedule was communicated to the pilots. After a detailed briefing and signing informed consent, the pilots completed the questionnaire. Approval for the study was obtained by the Ethical Research Committee of the Belgian Defense and of Ghent University Hospital. All pilots present participated and were included in the study. The participating percentage reached approximately 70%. Pilots were divided in two groups: a neck pain group (NPG) and a healthy group (HG). The NPG contained pilots with more than two episodes of neck pain which lasted for at least one day the past 12 months.
Questionnaire
The questionnaire was divided into three parts: a general, a work-related, and a pilot-specific part. The general part, based on the Dutch Musculoskeletal Questionnaire [18], was comprised of questions concerning personal information, health, leisure activities, neck pain, and the Neck Disability Index (NDI) [26]. Personal information consisted of questions about age, gender, height, weight, smoking habits, sleeping hours, and highest military ranking. The neck pain part of the questionnaire contained questions about the cause, the progress, and the characteristics of the neck pain.
In addition to questions about breaks, years at current job, work hours per week, and computer use, the work-related part was subdivided into physical (physically tired at the end of the day, postures, and movements) and psychosocial (mentally tired at the end of the day, job satisfaction, prospects, and job pressure) factors. The pilot-specific part contained questions about flight experience (number of flight hours, use of night vision goggles, type of airplane, flight circumstances), preventive measures (strength training, stretching, use of head rest, and prepositioning of the head), and flight-related causes of neck pain. A preface explained the aim of the survey and gave instructions on properly filling out the questionnaire, which was imported into Microsoft Office Access 2003. Neck pain was defined as pain in the head and neck region; a drawing with shading in the head, neck, and shoulder area, was shown to the subjects (Fig. 1) [9].

Figure 1. Drawing of the head, neck, and shoulder area with a shaded head and neck region indicating ‘neck pain’.

Statistics
Statistical analyses were performed with SPSS 12.0 software package (SPSS Inc., Chicago, IL) for Windows. Differences between groups were calculated by cross-tabulations, a one-way-ANOVA, an independent samples t-test or a Mann-Whitney U-test (if normal data distribution was not obtained). Mean differences with 95% CI were given as descriptive statistics. In all tests, P < 0.05 was considered statistically significant.
Individual, work- and flight-related issues in F-16 pilots reporting neck pain

Results

The one-year prevalence of self-reported neck pain in F-16 pilots was 18.9% (N=17). A total of 47% (N=8/17) of the NPG had complaints at the moment of completing the questionnaire and 12% (N=2/17) reported continuous pain. The pain behavior during the worst episode of pain was described as follows: “neck pain disappeared without complications after a few days”, 12% (N=2); “neck pain was not healed and occasionally recurred”, 41% (N=7); and “severity of neck pain got worse”, 41% (N=7). One pilot did not indicate the pain behavior because he experienced a much worse episode of neck pain shortly before the beginning of the study, which was still there as he completed the questionnaire. In answer to the question ‘what caused your neck pain?’ stress at the work place accounted for 12% (N=2); a sudden movements, 47% (N=8); and cause unknown, 41% (N=7). One pilot had neck pain that radiated to the shoulder combined with headache; in the remaining pilots, 18% (N=3/17) reported radiation to the shoulder, 12% (N=2/17) to the wrist, and 18% (N=3/17) had a headache. None of the pilots had ever been diagnosed with an intervertebral disk hernia. The mean score of the NDI, 3.4 (CI 0.8-6), did not reach the cut-off for mild disability (score 5) in the NPG.

Table I: Mean flight hours reproduced for the healthy (HG) and the neck pain pilots group (NPG).

<table>
<thead>
<tr>
<th></th>
<th>HG, N=73</th>
<th>95% CI*</th>
<th>NPG, N=17</th>
<th>95% CI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flight time</td>
<td>1613</td>
<td>646-2581</td>
<td>1745</td>
<td>826-2666</td>
</tr>
<tr>
<td>Total F-16 time</td>
<td>984</td>
<td>210-1758</td>
<td>962</td>
<td>408-1516</td>
</tr>
<tr>
<td>Weekly F-16 time</td>
<td>3.3</td>
<td>1-5.6</td>
<td>2.6</td>
<td>1.4-3.8</td>
</tr>
</tbody>
</table>

*Confidence intervals

Details about flight hours are described in Table I. The NPG reported no more flight hours than the HG. A total of 44% (N=40/90) of the pilots used NVG. Flight hours with NVG fluctuated from 1 h to 300 h. An average flight with NVG lasted 74 min (CI=51-105). The NPG reported no more flight hours with NVG than the HG. Of the NPG, 41% (N=6/17) received a flight restriction because of their neck pain; grounding varied from one week to one month (9.8 d, CI 0.6d – 19d). Pilots were asked about their preventive strategies. Results are reproduced in Table II. The reported preventive strategies of the HG were not different from the NPG.
Prevention of flight-related neck pain in military aircrew

Table II. Preventive strategies classified by healthy (HG) and neck pain pilots groups (NPG).

<table>
<thead>
<tr>
<th>Preventive measures</th>
<th>HG N=73</th>
<th>NPG N=17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength training</td>
<td>4/73 (5.6%)</td>
<td>3/17 (17.6%)</td>
</tr>
<tr>
<td>Pre-flight stretching</td>
<td>41/73 (56.9%)</td>
<td>13/17 (76.5%)</td>
</tr>
<tr>
<td>Post-flight stretching</td>
<td>5/73 (6.9%)</td>
<td>3/17 (17.6%)</td>
</tr>
<tr>
<td>Head against head rest</td>
<td>13/73 (18.1%)</td>
<td>2/17 (11.8%)</td>
</tr>
<tr>
<td>Pre-positioning</td>
<td>51/73 (70.8%)</td>
<td>14/17 (82.4%)</td>
</tr>
<tr>
<td>one movement plane</td>
<td>15/73 (20.8%)</td>
<td>4/17 (23.5%)</td>
</tr>
</tbody>
</table>

In the NPG, 77% (N=13/17) of the pilots indicated that their complaints started with flying the F-16. These pilots reported that complaints occur most likely during air combat maneuvering and basic fight maneuvering sorties without NVG and a G level exceeding 4 Gs. The maneuvers that induced the complaints were described by the NPG as the “Check-six” maneuver and turning the head towards the rear of the plane. The complaints started during the flight in 46% (N=6/13) of the NPG; and remained until the end of the flight for all pilots. In the remaining 54% of the NPG, the complaints started after the flight. The beginning of the pain varied between 10 minutes to 3 hours after the flight. In both cases, complaints disappeared after a few days.

In the NPG, 41% were younger than 30 year of age, 56% were between 30 and 39 year, and 3% were between 40 and 49 year. In the HG, 47% were younger then 30, 47% were between 30 and 39 year and 6% were between the age of 40 and 49. Mean body mass index (BMI) in the NPG was 24 (CI=21.4-27) and in the HG 24 (CI=22.5-25.7). No differences with regards to individual factors were found.

No significant differences were found in leisure and sports activities of both groups. The pilots practiced sports for 1–3 hours per week. The most popular sports were going to the gym (36%) and running (24%). No differences with regards to work experience were seen. For all subjects, the mean duration of employment was 8 year (3.3-12.7) with a mean of 41 (CI=28.3-43.7) working hours per week and a 5-day working week. All pilots in the NPG reported that their complaints started during their current job.

The NPG reported more often that their job demanded lots of force (P=0.002) and that at the end of the day they were physically tired (P=0.002). The NPG were often holding their neck in a forward bent posture (P=0.014) and were often sitting for a long time (P=0.045). The NPG reported more hours of computer work time per day (P=0.050, CI= 3.2 h/d, CI 4.6-1.8). No other physical work-related differences were found. The NPG reported significantly more that they were mentally tired at the end of the day (P=0.01) and that they were annoyed by others at their job (P=0.001). No other psychosocial work-related differences were found.

The number of pilots with neck pain seeking therapy in the previous 12 months was
Individual, work- and flight-related issues in F-16 pilots reporting neck pain

relatively low. Only 24% (N=4/17) of the pilots consulted a physician and 75% of those (N=3/4) followed therapy. Physiotherapy was the most popular treatment (massage and mobilization). None of them receive active therapy, i.e., a structured rehabilitation program including specific exercises. No medication was taken.

Discussion

Pilots were asked if they had neck pain during the preceding 12 months. A total of 42.2% had experienced neck pain. Only 18.9% experienced more than two episodes of neck pain which lasted for at least one day during the past 12 months. This was much lower than in other studies concerning this issue [27]. In the 1980s, Bieseman et al. [8] conducted a survey in which a sample of 30 F-16 pilots participated; 50% of them reported having neck problems due to flying the F-16. In the same period, Vanderbeek et al. [25] reported minor neck injuries in 61% of operational F-16 pilots over a 3-months period. Ten years later Albano et al. [1] reported a one-year prevalence of 56.6%. In the literature, the neck pain prevalence rate in F-16 pilots varies widely; this could be attributed to the differences in the method of reporting neck pain, the differences in type of missions, newer equipment, and the adopted style of flying during the years. Yacavone et al. [27] defined cervical injuries as at least one day absence from the flight schedule, and brought the incidence of neck injuries in pilots of high performance aircrafts back to 26.8%. Literature described possible causes for higher prevalence: the F-16 pilot’s neck is in flexion in order to maintain a normal direction of gaze in relationship to the horizontal plane because of the 30° declination of the seat [19]. More specifically, an additional 15° forward flexion of the neck to the trunk is required [10]. Therefore the prevalence of neck injury seemed to be significantly higher in F-16 pilots than in F-15 pilots. Differences in type of aircraft have an effect on the occurrence of neck injury [25].

Based on the literature, only F-16 flight hours were taken into account since the other aircraft exposed pilots only to low G forces [19,20]. In the current study, the quantity of F-16 flight hours seemed to have no influence on the occurrence of neck pain. Our results are in agreement with Albano et al. [1], who reported no differences in total F-16 hours between injured and uninjured pilots concerning F-16 flight hours. Hämäläinen et al. [16] indicated that the number of flight hours was associated with experiencing acute in-flight neck pain.

In the current study, 41% (N=7) of the NPG received a restriction to fly due to their neck complaints. This restriction varied from one week to one month. Literature percentages of flight restriction were hard to compare due to differences in methodology. Newman et al. [23] reported that 7% of all F/A-18 pilots were taken off flying duties for an average period of 2 weeks. Kikukawa et al. [20] reported that due to continuing symptoms, 16
of the 129 F-15 pilots were removed from the flying mission for an extended period of time. Drew [11] reported that 48% of F-16 pilots were grounded once as a result of their neck pain. Others reported mean restriction periods of 0.8 days [1], 3 days [21] and 4 days [8].

The NPG described that the “check-six” was the most common maneuver which elicited their neck pain. This maneuver regularly demands the maximum amplitude of rotation in the pilot’s neck, often combined with lateral bending flexion and extension; this is an extreme deviation from the normal axial alignment of the neck. This is a vulnerable position for the pilot’s neck, especially when it was combined with the $+G_z$ [1;19;20]. Häämäläinen et al. [14] conducted a study in which they assessed the effect of $+G_z$ forces and head movement on the cervical erector spinae muscle strain. In the “check-six” position, the muscles’ capacity to protect the cervical spine was the lowest.

Fighter pilots were questioned about their preventive precautions for neck injury. Prepositioning the head prior to the onset of high $+G_z$, was the most reported strategy to prevent neck pain. In the current study, no significant differences were shown in the occurrence of neck pain between pilots using and those not using this strategy. However, other studies show evidence that prepositioning the head appeared to prevent minor neck injuries. Placing the head against the canopy was another preventive strategy described in the literature [1]. The questionnaire in the current study revealed that 57% of the HG and 77% of the NPG perform stretching, immediately before walking to their jet or in the cockpit before take off, almost as a routine. However, the distribution between the HG and the NPG was not different. Our results are in line with previous studies that concluded that preflight stretching may not be protective in terms of G-induced neck injury [19;23].

Traditionally, neck muscle strength training has been recommended and discussed extensively for the prevention of neck pain in this population [1;5;20].

Recent research, which counted fewer subjects than the current study, supports neck strengthening exercises based on the fact that fighter pilots with neck pain had significantly lower neck muscle strength [5]. The results of the current study, however, which are consistent with those of Newman, show no differences in the occurrence of neck pain between pilots who performed unsupervised neck strengthening exercises and those who did not [23].

No differences were found with regards to individual factors. This is in contrast with Albano et al. [1], who found that the BMI was higher in uninjured pilots. Our results are in accordance with the results of Häämäläinen et al. [16], who found no anthropometrical differences.

No differences with regards to exercise habits were reported between the NPG and the HG. The most popular sports could be categorized under whole body exercises. Some contradictions exist on the preventive effect of this kind of exercise with regards to a diminution of acute in-flight neck injuries. Albano et al. [1] did not find that whole
Individual, work- and flight-related issues in F-16 pilots reporting neck pain

Body exercises were associated with reduced neck injuries, and Newman et al. [23] indicated that general muscle resistance training alone was not the definitive answer for the prevention of $+G_z$-induced neck injuries. In contrast, Hämäläinen et al. [15] indicated that whole body endurance training was protective.

In the current study, all pilots reported that their complaints started during their current job. In the study of Kikukawa et al. [20], 93.8% of the pilots circumscribed their neck problem as an occupational disease. The NPG in the current study reported significantly more that the following work-related factors could be related to neck pain: high force demands, often sitting for a long time, frequently holding the neck in a forward bent posture, and being physically tired at the end of the day. These factors are also described as risk factors in non-flying occupational environments [4;6;9]. Besides the physical factors, the NPG in the current study reported significantly more psychosocial factors such as being mentally tired at the end of the day and being annoyed by others at the workplace. This is in agreement with the fact that stress at the workplace was given as one of the other causes of neck pain reported by the pilots of the NPG. In other studies, concerning nonflying work environments, these factors were recognized as possible risk factors in the development of neck pain [3;7;9;24]. The pilots participating in this study reported a 40-h week, working 5 days per week. Taking the reported flight hours into account, a normal working week comprises almost 90% nonflying activities (mission planning, briefings and debriefings, preparing materials, and administration). Perhaps the contributing role of physical and psychosocial nonflying job characteristics to neck pain was underestimated in other studies. The current study illustrates that taking them into account is very important. Some of these factors such as high force demands and often holding the neck in a forward bent posture are factors fitting in the dynamic F-16 work environment. More hours of computer work time per day were recorded in the NPG. Other studies investigated the use of the keyboard during work time; they found that 4-6 hours of keyboard use per day increased the risk of neck pain [22]. Only 23.5% of the pilots who reported neck pain consulted a physician. This is rather low, but these findings were similar to other studies. Newman et al. [23] reported that 27% of the pilots had sought for medical attention during their career. A survey conducted by Drew et al. [11] showed that 43% of the F-16 pilots sought medical attention. In both studies treatment included rest, medication, and/or physiotherapy. Because repeated neck injury results in premature chronic degenerative changes in fighter pilots and because a history of neck pain is a risk factor for relapse, early reporting and treatment are necessary [1;10;17].

This study is limited by its retrospective nature; it relied on the memory of the pilots over a period of one year. There were 90 F-16 pilots who participated; only 17 of them experienced neck pain, and this could form a limitation to the conclusion drawn. The current study did not monitor the flying abilities and the different movement strategies of the pilots during flight. Pilots were informed about this study in advance by a medical
briefing; participation was voluntary, which could create a bias. However, the advance briefings and the fact that the survey was anonymous were likely to have encouraged participation. The questionnaire was protected; pilots were obligated to complete the whole questionnaire.

The one-year prevalence of neck pain in F-16 pilots was 18.9%. It appeared that in 47% of the pilots, neck pain was caused by a sudden movement and 77% reported that their complaints started due to the flight. Besides the flexed head position and the fact that the NPG reported their work to be physically demanding, no other flight-related issues were found. However, this study inquired not only about the flight-related factors of these high-performance pilots, it also took their other work-related factors into account. Being physically and mentally tired at the end of a normal working day, often sitting for a long time, and being annoyed by others at their job were work-related factors in which the healthy and the neck pain group significantly differed. Since the specific flight-related factors were not significantly different between the healthy and the neck pain group, physical and psychosocial factors could have contributed to the development of neck pain in F-16 pilots. This might signify that the flight was just the trigger needed to educe their complaints and that other physical, psychosocial, and work-related factors could have contributed to the development or maintenance of neck pain in F-16 pilots.
References

Individual, work- and flight-related issues in F-16 pilots reporting neck pain
Functional assessment of the cervical spine in F-16 pilots with and without neck pain

Chapter 3

Veerle De Loose, Marieke Van den Oord, Frédéric Burnotte, Damien Van Tiggelen, Veerle Stevens, Barbara Cagne, Lieven Danneels, Erik Witvrouw

Aviation, Space, and Environmental Medicine 2009;80:477-481
Abstract

Introduction: Spinal symptoms in fighter pilots are a serious aero medical problem. The most common neck complaints are muscular pain and strain. The aim of the current study was to determine possible differences in the cervical range of motion (CROM), neck position sense, and neck muscle strength between pilots with and without neck pain.

Methods: There were 90 male F-16 pilots who volunteered, of which 17 had experienced bilateral neck pain. A standardized questionnaire was used to collect personal information. The maximum isometric neck flexion/extension and lateral flexion strength, the neck position sense, and the cervical range of motion were measured.

Results: There were no significant differences between healthy pilots and those with neck pain concerning neck muscle strength and neck position sense. The neck pain group had a limited CROM in the sagittal plane (130°; CI: 116°-144°) and in the transversal plane (155°; CI: 140°-170°) compared to the healthy pilots.

Discussion: In the current study we screened for different motor skills so that deficits could be detected and retraining programs could be implemented when necessary. According to our results, individual retraining programs might reduce neck pain and therefore a well-instructed training program to maintain a proper active CROM should be implemented. Future studies should investigate the effectiveness of this kind of programs.
Functional assessment of the cervical spine in F-16 pilots with and without neck pain

Introduction

Neck pain in association with the dynamic work environment of the fighter pilot is a well-discussed issue. Spinal symptoms in these pilots have been recognized as a serious medical problem [2;21;25]. The most common neck complaints are muscular pain and strain. Electromyography (EMG) investigations have been able to show that pilots exposed to high G forces over repeated, short periods use close to 100% of their neck extensor muscle strength. When in-flight EMG recordings of the cervical muscles were analyzed, investigators found higher demands on strength and endurance in pilots than in the average person [15;26]. Often described, flight-specific contributing factors of neck pain in the pilot population are head movements under high +Gz load, seat-back angle, forward bent posture, head worn equipment, the use of night vision goggles, and numbers of flight hours [14;15]. According to the literature, pilot’s lack of muscular force and endurance of the cervical musculature could be one of the main risk factors causing neck pain. As a consequence, neck strengthening exercises are often recommended in the prevention of neck complaints in fighter pilots [5;11;31]. Although, other motor control impairments such as lack of range of motion, poor proprioception or muscular coordination and muscular imbalance could also play an important role in the occurrence of neck pain [6;7].

In the current study a battery of tests was developed for the functional assessment of the cervical spine in order to provide a proper preventive training program for F-16 pilots. Our study was based on the injury prevention research by Van Tiggelen et al. [32]. In that study, the authors declared that prior to introducing preventive measures to the pilots, the etiology and consequences of the neck pain in this population need to be identified. The preventative measures must be based upon the data collected during the functional assessment of the cervical spine.

Therefore, the main purpose of the current study was to determine possible differences in the cervical range of motion (CROM), neck position sense, and the neck muscle strength between pilots with and without neck pain.
Methods

Subjects
The current study was a collaborative effort between the Belgian Air Force and the Royal Netherlands Air Force, both of which operate the F-16 Fighting Falcon. The squadrons received a medical briefing introducing the study. There were 90 F-16 pilots who signed informed consent forms and participated in this study. The Ethical Research Committee of the Belgian Defence and the Ghent University Hospital obtained approval for the study.

All tests were performed on the same day and the pilots were instructed not to fly on the day of the test. The anonymity of the participating pilots was guaranteed by using a unique identifying code. A standardized questionnaire was used to collect information concerning anthropometrical properties, hand dominance, the frequency of exercising, number of flight hours, use of night vision goggles, nature of neck pain, prevention strategies and treatment. Pilots were divided in two groups: a neck pain group (NPG) and a healthy group (HG). To be eligible for the neck pain group, pilots had to have experienced more than two episodes of neck pain lasting at least one day during the past 12 months [9;12;13]. More details about the self-reported one-year prevalence of neck pain in these pilots were published previously [13].

Table I summarizes the groups’ anthropometrical data and the weekly frequency of exercising. Table II summarizes the flight profiles.

Table I. Summary of groups’ anthropometrical data and the weekly frequency of exercising.

<table>
<thead>
<tr>
<th></th>
<th>HG§</th>
<th>95% C.I.*</th>
<th>NPG¶</th>
<th>95% C.I.*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age categories</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger than 30</td>
<td>47%</td>
<td></td>
<td>41%</td>
<td></td>
</tr>
<tr>
<td>Between 30 and 39</td>
<td>47%</td>
<td></td>
<td>56%</td>
<td></td>
</tr>
<tr>
<td>Between 40 and 49</td>
<td>6%</td>
<td></td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td>24</td>
<td>22.5-25.7</td>
<td>24</td>
<td>21.4-27</td>
</tr>
<tr>
<td><strong>Body height</strong></td>
<td>181</td>
<td>175.1-186.9</td>
<td>182.1</td>
<td>176-188.2</td>
</tr>
<tr>
<td><strong>Body weight</strong></td>
<td>79.3</td>
<td>69.6-89</td>
<td>80.5</td>
<td>69.3-91.7</td>
</tr>
<tr>
<td><strong>Weekly frequency of exercising</strong></td>
<td>3.3</td>
<td>1.3-5.3</td>
<td>2.6</td>
<td>4.1-1.1</td>
</tr>
</tbody>
</table>

§ Healthy group ¶ Neck pain Group * Confidence interval
Table II. Summary of groups flight profiles.

<table>
<thead>
<tr>
<th></th>
<th>HG $\S$</th>
<th>NPG $\P$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours</td>
<td>95% C.I.$^*$</td>
</tr>
<tr>
<td>Total Flight time</td>
<td>1613</td>
<td>646-2581</td>
</tr>
<tr>
<td>Total F-16 time</td>
<td>984</td>
<td>210-1758</td>
</tr>
<tr>
<td>Weekly</td>
<td>3.3</td>
<td>1-5.6</td>
</tr>
<tr>
<td>Years fighter pilot</td>
<td>9.5</td>
<td>4.1-14.9</td>
</tr>
</tbody>
</table>

$\S$ Healthy group; $\P$ Neck pain Group; $^*$ Confidence interval

**Strength**

The maximum isometric neck muscle strength was measured with a David F-140 device (David International, Ltd., Germany). The subjects were sitting in an upright position with stretched legs, only the heels touched the floor and the arms remained relaxed against the side of the body. The seat height, motion axis of C7-T1 (in line with the axis of the movement arm of the testing unit), and chest support were adjusted for each subject. Before any measurements were taken, the subjects performed standardized warm-up exercise for the neck and shoulders. The isometric tests were performed in four directions: flexion, extension, and left and right lateral flexion. The subjects were encouraged to press their head against the resistance pad with increasing force up to the maximum voluntary contraction of 6 seconds. Within one series there were 30 seconds of rest; between the different directions there was a rest period of 3 minutes. Three maximum voluntary isometric contractions (MVIC) were executed in each direction, the highest peak value (Nm) was used for further analysis. The reproducibility and reliability were confirmed by pilot tests on 15 healthy civilian volunteers. The single-measure ICC ranged from 0.94 to 0.95 for the peak value (Nm) of the different strength tests for both the reproducibility and the reliability.

**Neck Position Sense**

The neck position sense was measured with the three-dimensional motion analyzer Zebris CMS20, using Windata version 2.20 (Zebris Medizintechnik GmbH, Isny, Germany). This analyzer consists of a helmet and a triple trunk, each with three ultrasound microphones. The subjects were blindfolded and seated in an upright position on a stool without backrest. Their hands were placed on the thighs; hips and knees were bended 90°. The point of departure was that the pilots defined the neutral position of his necks. The test consisted of two parts. In the first part, the pilots were instructed to return to their own neutral position after an active submaximum range cervical flexion-extension and right and left rotation. In the second part, the pilots were asked to return to a position defined by a researcher (30° right or left rotation). For the
first part the absolute reposition error was calculated in the sagittal plane and transversal plane as a mean of 10 repetitions. For the second part the absolute reposition error was calculated in the transversal plane for right and left rotation as a mean of 5 repetitions in each direction. The reproducibility and reliability were confirmed by pilot tests on 15 healthy civilian volunteers. The exact single-measure ICC for the reposition error to the neutral position was 0.87 for the reproducibility and 0.72 for the reliability. For the absolute reposition error in the repeated-matching test to 30° rotation the exact ICC for the reproducibility was 0.67 and for the reliability 0.61.

**Range of Motion**
The active cervical range of motion (CROM) was measured with the three-dimensional motion analyser Zebris CMS20, WinSpine version 1.79 (zebris Medizinetchnik GmbH, Isny, Germany). The subjects were positioned as above for the neck position sense but without the blindfold. To be sure that the subjects’ departure position between the different movement directions was the same, a narrow mirror was placed so that the subject was able to see his own eyes in this position. The device was calibrated before the start of the first movement. After every movement the subject was asked to look at their eyes in the mirror. The maximal full CROM was measured for flexion-extension, right-left rotation, and right-left lateral flexion. Each measurement consisted of three repetitions for each movement. For each direction the mean of three repetitions was recorded. The repeatability and reproducibility of the CROM test is described by Cagnie et al. [10] and was shown to be highly reliable. ICC ranged from 0.92 to 0.94 for the reproducibility and ranged from 0.80 to 0.87 for the repeatability. The different parts of the functional assessments were conducted in an arbitrary sequence. To avoid the influence of muscular fatigue on the other tests, the muscular strength was always measured at the end of the evaluation. Each assessment had two permanent examiners; they were blinded to the pilots’ history of neck pain.

**Statistics**
Statistical analyses were performed with SPSS 15.0 software package (SPSS Inc., Chicago, IL). Mean differences with 95% CI were given as descriptive statistics. In all tests, p < 0.05 was considered statistically significant. All data were normally distributed (Kolmogorov-Smirnov test and Levene’s test). Parametric statistics were applied. Independent sample’s t-tests were performed to analyze differences between healthy and neck pain pilots concerning the strength and the mobility. For analysis of the reproducibility and the repeatability, intraclass correlation coefficients (ICC) were used.
Results

There were no significant differences between the HG and the NPG pilots concerning neck muscle strength. The mean value for HG and NPG, respectively, were as follows: extension muscles, 60Nm (CI: 44-76) and 56Nm (CI: 40-72); flexion muscles, 26Nm (CI: 16-46) and 25Nm (CI: 15-35); right lateral bending muscles, 31Nm (CI: 16-46) and 33Nm (CI: 18-48); left lateral bending muscles, 31Nm (CI: 17-45) and 31Nm (CI: 17-45).

There were no significant differences between the HG and the NPG concerning neck position sense. After a submaximal flexion-extension movement the mean reposition error in the sagittal plane for the HG measured 2.83° (CI: 1.51-4.15), and 2.64° (CI: 1.38-3.9) for the NPG. After a submaximal right and left rotation the mean reposition error in the transversal plane for the HG measured 2.1° (CI: 0.91-3.29) and 1.68° (CI: 1.22-2.14) for the NPG.

There were no differences in neck position-matching accuracy when the pilots performed the test to the neutral position or to the 30° rotation. The reposition error in the transversal plane for the HG and the NPG, respectively, were as follows: return to 30° rotation on the right side 2.51° (CI: 1.27-3.75) and 2.62° (CI: 1.41-3.83); return to 30° rotation on the left side 2.67° (CI: 0.72-4.62) and 2.28° (CI: 1.34-3.22).

The only statistically significant difference between both groups was that the NPG had a decreased CROM in both the sagittal plane (p=0.012) and in the transversal plane (p=0.044) compared to the HG. The mean CROM for the HG and NPG, respectively, were as follows: sagittal plane, 140° (CI: 125-155) and 130° (CI: 116-144); transversal plane 162° (CI: 148-176) and 155° (CI: 140-170); frontal plane, 87° (CI: 71-103) and 89° (CI: 73-105).

Discussion

Neck pain and relatively minor cervical spine soft-tissue injuries have been frequently described in fighter pilots [3;22;30]. Another well-documented problem in the fighter pilots cervical spine is the premature onset of degenerative changes in the cervical spine [18;19]. As a result, deficits in the motor skills of the fighter pilots cervical spine can be expected [6].

In the current study the maximum isometric neck muscle strength was measured. No significant differences were observed between the healthy and the neck pain pilots. These results confirm findings of previously published studies [2;16].

Some studies suggest that increased muscle strength may reduce muscle strain under +Gz loading. Based on the observation that fighter pilots with neck pain had significantly less neck muscle strength, neck-strengthening exercises were encouraged [5]. Oksa et al. [26] support neck-strengthening exercises after observations of in-flight EMG.
measurements because the magnitude of the peak strain level was extremely high. This emphasizes the fact that neck musculature of fighter pilots is subjected to very high demands. They concluded that repeated sorties, such as aerial combat maneuvering exercises several times a day, cause fatigue. This muscle fatigue was most noticeable in the neck musculature [27]. Strengthening programs have been suggested to decrease the fatigability of the pilot’s neck musculature. Some specific neck strengthening programs in fighter pilots have resulted in increases in neck muscle strength [2;5;31]. Burnett et al. [8] concluded that the natural strength adaptation of the cervical muscles to the +Gz environment associated with flight training is rather limited. To cope with the loads placed on the cervical spine during more advanced high-performance flying, a specific neck-strengthening program was recommended for the pilots throughout the flight-training course.

In the current study no differences were observed between the healthy pilots and those with neck pain regarding the neck position sense in the sagittal and the horizontal plane. These results are in agreement with other neck position-sense investigations. These other studies did not observe any differences in the neck position-sense accuracy between neck pain patients and healthy individuals [7;29]. In contrast, other researchers did observe greater reposition errors in the subjects with pathology of the cervical spine [23;28]. However, the population of the latter studies had more serious pathology than our neck pain pilots. In the current study, the position within the range of motion did not influence the position-sense accuracy. These findings are in agreement with the findings of Armstrong et al. [7]. Little has been published concerning the effects of position-sense retraining. To the best of our knowledge, no literature is available concerning neck position-sense retraining and fighter pilots.

In our study we observed limitations in the CROM in the sagittal and the transversal plane in the NPG. No differences in the frontal plane were observed. These results are in agreement with those of Armstrong et al. [7], who investigated the differences in CROM between whiplash patients and healthy individuals. Whiplash patients displayed significantly less flexion, extension, and left and right rotation, and no significant differences were observed when comparing lateral flexion recorded with the healthy group [7]. We used the same study design as Cagnie et al. [10], who observed a limitation in the CROM in the transversal plane in individuals with idiopathic neck pain compared to healthy subjects. The results of our study are in contrast with the results of previous studies concerning CROM in fighter pilots. These other investigators concluded that the groups with and without experience of acute in-flight neck pain did not differ concerning the CROM [16;17]. One has to bear in mind that other methods were used, e.g., subjects were student fighter pilots and the passive CROM was measured.

The reason for the limited CROM in the neck pain group is unknown. Possible suggestions are that the decrease might be caused by shortened neck musculature or degenerative changes brought on by flying high-performance aircraft.

Stretching is generally believed to promote better performance of the neck muscles,
which is necessary during high +Gz flight to prevent acceleration-induced neck injuries [11, 26, 27]. There are contradictory opinions on this, however. Several authors suggested that stretching had a beneficial effect on injury prevention, while others suggested that stretching before exercise did not prevent injury [4].

In a previous study, fighter pilots were questioned about their current preventive measures for neck injury. This questionnaire revealed that pilots routinely performed stretching before flying. Yet, pilots who performed preflight stretching had no fewer complaints than those who did not [13]. Newman [25] concluded that preflight stretching might not be protective in terms of G-induced neck injury. In the survey of Jones et al. [20], preflight stretching did not appear to prevent flight related pain; however a more defined preflight stretching routine was recommended as a part of a potentially effective prevention strategy. One survey of 268 pilots showed that preflight range-of-motion stretching had a beneficial effect [1].

The current study revealed that the active CROM was limited in the sagittal and the transversal plane in the neck pain pilots. Little has been published about the changes in the CROM following stretching exercises. McCarthy et al. [24] examined the effect of a stretching program on the active cervical rotation. Stretching exercises for the cervical spine did increase the active CROM in the transversal plane. Importantly, to maintain this effect these stretching exercises must be performed regularly. This might indicate that stretching, as a part of an effective preventive strategy, could contribute significantly. The evidence regarding the effect of stretching on pain is unclear [4]. However, according to our results, a well-instructed stretching program could be implemented in the fighter pilots training program in order to maintain a proper active CROM.

As mentioned above, different approaches to the prevention of neck pain in fighter pilots have been shown to have their benefits. As not all pilots develop neck pain, not all pilots will have benefits from these approaches. The strength of the current study is that it assessed different motor skills of the fighter pilots cervical spine. To the best of our knowledge this is the first study in this population that combined the assessment of different motor skills. Thus, deficits could be detected and retraining programs could be implemented when necessary. This kind of individual retraining programs might reduce neck pain. Additional studies to investigate the effectiveness of this type of program in this population are needed. These programs should take the high in-flight demands on the fighter pilots cervical spine into consideration.

The present results must be viewed within the limitations of the study. Only 17 of 90 F-16 pilots experienced neck pain; this could form a limitation to the conclusion drawn. The current study did not monitor the flying abilities and different movement strategies of the pilots during flight.

The current study established that many factors can contribute neck pain in F-16 pilots. No general preventive program exists that will suit all pilots; therefore an individualized program should be introduced. Future research should evaluate the effectiveness of the implemented interventions.
References

[18] Hanada R, Kitadda A, Yoshihara Y, Tachibana S, Nagaoki H: Neck pain and


Neck pain in military helicopter pilots: Prevalence and associated factors

Chapter 4
Abstract

Our aim is to estimate the self-reported one-year prevalence of neck pain in military helicopter pilots and to compare work-related, individual and health-related factors in the pilots with (neck pain group) and without (reference group) regular or continuous neck pain. A questionnaire was completed by 75% (n = 113) of all military helicopter pilots of the Royal Netherlands Air Force and Navy.

The reported year-prevalence of any neck pain was 43%, and 20% for regular or continuous neck pain. Besides some significant differences in individual and health-related factors (also often reported in the general population), flying hours were significantly higher in pilots with neck pain compared to their colleagues without neck pain.

The findings in this study suggest that neck pain in military helicopter pilots is a significant occupational problem and may be a consequence of longer exposure to flying.
Neck pain in military helicopter pilots: Prevalence and associated factors

Introduction

Neck pain in military pilots has been a subject of research for many years. The focus, however, has primarily been on neck pain among pilots flying high performance jet aircraft [13;17;22;27]. In the past decade, neck pain among helicopter pilots has been discussed in the literature [4;5;21], with the reported prevalences ranging from 29% to 57% [3;6;24].

In the general population, neck pain is thought to be multifactorial, suggesting that there are a number of risk factors contributing to its development. Health-related factors such as previous pain episodes, pain in body regions related to the neck, and physical and mental fatigue at the end of the working day have been reported as risk factors in the non-military population [7;10;19]. Other factors that have been associated with neck pain in the general population include individual factors such as age and gender, although these results have not been consistent [9;10;23]. Furthermore, work-related factors such as computer use and insufficient job satisfaction have been reported as potential risk factors [7;11].

The role of military pilot has specific job demands, and among these, several contributing factors have already been identified in the etiology of flight-related neck pain in pilots of jet aircraft [8]. However, flying a jet aircraft is not the same as flying a helicopter. Jet pilots are exposed more often to repeated high +Gz forces compared to helicopter pilots, and this exposure, together with extreme head positions and movements, has been identified as the primary risk factor for neck pain in these pilots [14;17]. When flying a helicopter, it is the ergonomic setting (with poor neck and body positions), whole-body vibration and heavy equipment worn on the head that have been suggested as risk factors for neck pain among helicopter pilots [25]. Research into these factors in neck pain in this population is limited, but is needed to enable preventative measures.

Our aim in this research is to estimate the self-reported one-year prevalence of neck pain in military helicopter pilots in the Royal Netherlands Air Force and Navy, and to compare work-related, individual and health-related factors in pilots with and without regular or continuous neck pain.
Methods

Subjects and Procedures
A total of 113 helicopter pilots, 103 males and 10 females, of The Royal Netherlands Air Force (RNLAF) and The Royal Netherlands Navy (RNLN), voluntarily completed an anonymous survey. Anonymity was assured with the use of codes to identify survey-takers. A verbal briefing introduced the study to all helicopter squadrons of the RNLAF and the RNLN, and the pilots received additional written information. Each squadron was then visited by the research team on three to four consecutive days, depending on the presence of the pilots (November 2006 – March 2008). The first author (M.VdO) was present on all visits. Only pilots who were on deployment, sick- or holiday leave were not reached and were thus excluded from recruitment. Almost all pilots present participated and all were on active flying duty (96% response rate). The 113 participants represented approximately 75% of all Dutch military helicopter pilots on active flying duty at the time of the survey. All pilots gave their written informed consent. Ethical approval for the study was waived because the questionnaires were anonymous and contained no material subject to privacy constraints.

The questionnaire was based on the standardized “Dutch Musculoskeletal Questionnaire” (DMQ), which was found to be valid [18]. The questionnaire was extended to include questions about flight-related issues and retrospective information on flight-related exposures. Pilots were asked to report to a member of the research team, who was housed in or near the squadron building. The researcher gave instructions to each pilot about the process of filling out the questionnaire, and the questionnaires were completed electronically, using Microsoft Office Access 2003. Typical time needed to complete the questionnaire was 20 minutes.

Table I shows the age-distribution and flight experience details for the sample. The mean (SD) body height, body weight and body mass index of the pilots were 183 (7) cm, 82 (11) kg and 24.4 (2.5) kg/m², respectively. At the time of the survey, 60 pilots flew transport helicopters for the RNLAF: (the ICH-47D Chinook (n = 20), the AS-532 U2 Cougar (n = 26), the Agusta-Bell 412 (n = 8), or the Alouette III (n = 6)). An attack helicopter, the (AH-64(D) Apache, was flown by 33 RNLAF pilots, and the Westland SH-14D Lynx helicopter, the RNLN transport helicopter, was flown by 20 pilots.
Neck pain in military helicopter pilots: Prevalence and associated factors

Table I. Mean values (SD) and median values (interquartiles) for years as military pilot, total flying hours, flying hours previous year and total number of NVG hours.

<table>
<thead>
<tr>
<th>Age</th>
<th>n</th>
<th>Years military helicopter pilot</th>
<th>Total flying hours</th>
<th>Flying hours previous year</th>
<th>Total NVG hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 30</td>
<td>6 (3)</td>
<td>867 (675)</td>
<td>168 (56)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30-40</td>
<td>10 (3)</td>
<td>1754 (919)</td>
<td>176 (63)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;40</td>
<td>21 (5)</td>
<td>3927 (1235)</td>
<td>130 (89)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>113</td>
<td>11 (6)</td>
<td>1836 (1407)</td>
<td>164 (68)</td>
</tr>
</tbody>
</table>

Median (IQR) | 9 (6 – 14) | 1300 (888 – 2581) | 180 (120 – 200) | 50 (0-100)

Values are given per age-category and for the whole sample (103 male pilots and 10 female pilots). NVG, night vision goggles.

Neck Pain

The outcome measure was self-reported neck pain in the previous year. Neck pain was defined as any pain, including aches and discomfort, and a diagram was used to illustrate and define specific body regions. On the basis of their responses to the pain question (response choices: never, occasional, regular or continuous), the pilots were further divided into the neck pain group (pilots reporting regular or continuous neck pain in the previous year) and the reference group (pilots reporting no or occasional neck pain in the previous year).

Work-related, Individual and Health-related Factors

Independent variables, below, in the analyses were selected based on our hypotheses as well as previous research.

- Individual factors: age (three categories were used in the analyses: <30 yr, 30-40 yr, >40 yr), gender, body height and body weight from which the body mass index (weight (kg) / height (m²)) was calculated.
- Health-related factors: reported physical and mental fatigue at the end of the working day (dichotomous: yes/no), doing specific neck strength exercises (yes/no), and co-morbidities that included history of neck pain in the preceding 12 months (yes/no) and pain in body regions related to the neck (shoulders, thoracic spine, and low back) in the previous year (no or occasional pain/regular or continuous pain).
- Work-related factors: type of helicopter, total flying hours, hours flown in the previous year, total hours flown with night vision goggles (NVG), and perceived relationship of neck complaints to flying. Pilots were asked to look up their specific flight hours in their flight log before they filled out the questionnaire. Pilots who never flew with NVG (n=29) were included in that analysis concerning NVG-hours with 0
hours. Other work-related factors were: duration of computer time per workday and general job-satisfaction (responses: good / reasonable, fair / mediocre, poor). For “type of helicopter,” three helicopter aircraft categories were used: 1) the Westland SH-14D Lynx helicopter, a transport helicopter flown by pilots of the RNLN; 2) the ICH-47D Chinook, the AS-532 U2 Cougar, the Agusta-Bell 412 or the Alouette III, all transport helicopters flown by pilots of the RNLAF; 3) The AH-64 (D) Apache, an attack helicopter flown by pilots of the RNLAF.

**Analyses and Statistics**

Statistical analyses were performed with SPSS 15.0 (Statistical Package of Social Science). The mean and standard deviation were used to describe normally distributed continuous data, otherwise the median and interquartiles were also stated to describe the 50th, and 25th to 75th percentiles. Differences between the neck pain group and the reference group were assessed with the chi-squared test for categorical data (type of helicopter, job-satisfaction, age, gender, specific neck strength exercises, physical and mental fatigue at the end of the working day, history of neck pain, and pain in body regions related to the neck). For numerical data (total flying hours, flying-hours previous year, total NVG hours, body height and body weight), independent samples t-tests were used or Mann-Whitney U tests when data distribution was not normal. A p value of ≤ 0.05 was considered statistically significant.

**Results**

The overall year-prevalence of any self-reported neck pain was 43 % (CI: 38%-48%) (n=49/113). Twenty percent (CI: 16%-24%) (n=22 / 113) of the pilots reported regular or continuous neck pain; this subset made up the neck pain group in this work. The neck pain group reported significantly more total flying hours (p=0.005), as well as more flying hours in the previous year (p=0.02), than the reference group. No significant differences in total NVG- hours were found between the two groups, although almost half of the neck pain pilots (9/22) reported that their neck pain was associated with NVG-use. **Table II** shows the total flying hours, flying hours in the previous year and total hours flown with NVG by group. Over 90% (20/22) of the neck pain group attributed their pain to flying, and of these 74% (14/20) indicated that their complaints started during flight. Considering the type of helicopter flown, 15% (3/20) of the pilots flying the Lynx helicopter, 28% (17/60) of the pilots flying one of the RNLAF transport helicopters and 6% (2/33) of the pilots flying the Apache helicopters reported regular or continuous neck pain in the prior 12 months. These differences were found to be significant ($\chi^2 = 7.0, 2$ df , $p = 0.03$). Among work-related factors other than flight-specific issues, no
significant differences were found between the groups in job satisfaction or duration of daily computer work. Across all pilots, the mean (SD) hours of computer work time per day was 3.1 (1.5) hours.

Table II. Total flying hours, flying hours previous year and total number of NVG-hours for the neck pain group and the reference group (male and female pilots together).

<table>
<thead>
<tr>
<th></th>
<th>Total flying hours</th>
<th>Flying hours previous year</th>
<th>Total NVG hours</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neck Pain Group</strong></td>
<td>Mean (SD)</td>
<td>2644 (1596)</td>
<td>197 (77)</td>
</tr>
<tr>
<td>(n = 22)</td>
<td>Median (IQR)</td>
<td>2635 (1063-3695)*</td>
<td>182 (178–222) †</td>
</tr>
<tr>
<td><strong>Reference Group</strong></td>
<td>Mean (SD)</td>
<td>1641 (1293)</td>
<td>156 (64)</td>
</tr>
<tr>
<td>(n = 91)</td>
<td>Median (IQR)</td>
<td>1140 (825-2000)</td>
<td>154 (120–200)</td>
</tr>
</tbody>
</table>

* Significant difference Neck Pain group compared to Reference group, p=0.005, † Significant difference Neck Pain group compared to Reference group, p = 0.02

The neck pain group reported a significantly higher incidence of physical fatigue at the end of the working day ($\chi^2 = 5.7$, 1 df, $p = 0.02$). Pilots were asked whether they performed specific strength exercises for the neck area. Thirty pilots (27%) actually performed such exercises, but they were proportionally not different represented in the neck pain group and reference group. When asked about any previous episodes of neck pain experienced more than 12 months ago, the neck pain group reported a significantly higher frequency of previous history of neck pain ($\chi^2 = 28.3$, 1df, $p<0.001$) compared to that in the reference group. The one-year prevalence of regular or continuous shoulder, thoracic or low back pain was 7% (n=8/113), 12% (n=14/113) and 26% (n=29/113), respectively. These data and the number of pilots with regular or continuous neck pain within these pain groups are shown in Table III. The pilots in the neck pain group reported higher prevalence of regular and continuous pain in shoulders ($\chi^2 = 5.5$, 1 df, $p = 0.04$) and upper back ($\chi^2 = 14.5$, 1 df, $p < 0.001$), but the prevalence of regular and continuous pain in the lower back was not different across groups.

No significant differences were found regarding body height, weight and BMI between groups. A significant trend was seen between the presence of regular or continuous neck pain and age ($\chi^2 = 6.7$, 1df, $p = 0.009$). Female pilots reported significantly higher prevalence of regular or continuous neck pain than did their male colleagues ($\chi^2 = 6.5$, 1 df, $p = 0.02$).
Table III. Number of pilots with regular and continuous shoulder, thoracic and low back pain and the number of cases with regular and continuous neck pain within these groups.

<table>
<thead>
<tr>
<th></th>
<th>Number of pilots</th>
<th>Cases of Neck Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder pain</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Thoracic pain</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Low back pain</td>
<td>29</td>
<td>9</td>
</tr>
<tr>
<td>Total (n)</td>
<td>113</td>
<td>22</td>
</tr>
</tbody>
</table>

Discussion

The findings in this study suggest that neck pain in military helicopter pilots is a significant occupational problem, and may be a consequence of longer exposure to flying; additional factors possibly relating to pain are older age, female gender, fatigue at the end of the working day, previous neck pain episodes and pain in shoulder and upper back.

While interpreting the results of this study, some consideration should be taken into account. The number of pilots in the neck pain group was too small to construct a logistic regression model, which would have allowed us to assess all risk factors related to regular and continuous neck pain, and mitigate the effects of confounding variables. The number of participants was limited by the size of the total population of military helicopter pilots in the Netherlands. The present sample covered all helicopter squadrons of the RNLAF and RNLN and only pilots on military deployment, holiday or sick leave were not included in the recruitment. Since almost all available helicopter pilots participated, which covered 75% of all military helicopter pilots on active flying duty, the present sample was considered representative for the population of the RNLAF and RNLN helicopter pilots.

Further, these self-reports of neck pain relied on the memory of the pilots over a period of one year. In addition, pilots are known to be reluctant to report physical complaints because of fear of restriction of flying. By having an independent research team administer the questionnaire at the pilot’s workplace instead of during the pilot’s periodic medical exams at the medical center, and by guaranteeing anonymity, we believe we have lessened pilots’ reluctance.

The overall one-year prevalence of any neck pain in military helicopter pilots was 43% (CI: 38%-48%), and 20% (CI: 16%-24%) for regular and continuous neck pain. Only a few previous studies have reported the prevalence of neck pain in helicopter pilots. The prevalence found in this study was lower than that of a previous Swedish study, where the 3-month prevalence of neck pain in helicopter pilots was found to be 57%, while 32% reported regular neck pain [3]. Two studies that focused on back pain among helicopter pilots, but also asked about neck pain in their survey, found a 12-month
Neck pain in military helicopter pilots: Prevalence and associated factors

prevalence of neck pain of 29% [24] and 48% [6]. Neither of those two studies made further distinctions in occasional versus regular or continuous neck pain. Prevalence of musculoskeletal pain often fluctuates from study to study because of different methodologies and criteria, which makes making an adequate comparison difficult. In a recent national Dutch survey on working conditions among approximately 22,000 Dutch workers in various jobs, definitions and outcome measures similar to ours were used [26]. The overall 12-month prevalence of any neck pain in that population was 55%, and 22% reported regular or continuous neck pain. The latter prevalence is similar to our findings, suggesting that helicopter pilots are at no greater risk for developing neck pain than the non-flying working population. However, the helicopter pilots in the current study were a selected population. Pilot candidates of the RNLAF and RNLN have to meet medical and physical standards, and our pilots are therefore assumed to be a population in better physical condition than the average worker. From this perspective, a lower prevalence of musculoskeletal pain would be expected, and these similar prevalence figures could thus indicate a relatively higher risk for neck pain in helicopter pilots.

That our sample came from a healthier than typical population was further confirmed by the relatively low prevalence of regular and continuous pain in the shoulder, upper back and lower back regions in our group. The neck pain group more often reported a history of neck pain more than 12 months ago compared to the reference group. Such previous pain episodes have been found to be an important risk factor in several neck pain surveys among the general population as well as in helicopter pilots [3;7;10;16]. Specific strength training for the neck area has been suggested to prevent neck pain in military jet and helicopter pilots [1;2;4]. In the current sample, only 27% of the helicopter pilots actually performed such exercises, but the percentages of these pilots were not different between the groups. In a systematic review, moderate evidence of benefit for neck pain patients was found when the stretching and strengthening exercises focused on the neck area [20]. However, evidence for the preventive effect of such exercises in a healthy population is scarce and should be an issue of interest in future studies.

When considering the individual factors, female pilots reported significantly more frequent, regular and continuous neck pain than their male colleagues did. The female pilots did not differ in age, flight-hours or NVG-hours compared to their male colleagues. In the general population, contrasting results have been published, although the majority of these studies indeed showed higher prevalence of neck pain for women than for men [19]. Females differ in neck anthropometry, with significantly smaller anthropometric parameters of the neck compared to size-matched (standing-height and neck length) males. Furthermore, females have 33% more head mass per unit neck muscle area than in size-matched males [28]. Taking into account the mass of the helmet and additional head-mounted displays that military pilots commonly use and the percentage of head mass per unit neck muscle area become even higher for females.
compared to males. This factor may play a significant role in the higher prevalence of neck pain in female helicopter pilots compared to their male colleagues.

Total flying hours and the flying hours in the previous year were significantly higher in the neck pain group compared to the reference group. In the Swedish study of military helicopter pilots, results of a multivariate analysis suggested that neither total flying hours nor flying hours in the previous year were found to be risk indicators for neck pain in the past 3 months [3]. Although that study did make a distinction between occasional and frequent neck pain, analyses were made with both groups combined. The difference between this occasional pain group and the pilots reporting no neck complaints might not have been distinctive enough to show an association. Furthermore, it was not clear in their study how many pilots attributed their neck pain to flying. In the current study, we chose to do our analyses with the outcome measure of “regular or continuous neck pain”. This allowed us to focus on the more serious cases of neck pain with respect to frequency and duration. In our study, only 22% of the pilots who reported occasional neck pain attributed their neck pain to flying, while 90% of the pilots who reported regular or continuous neck pain felt their neck pain was a consequence of flying. The association of flying hours with neck pain is in agreement with the study by Thomae et al. [24] on back pain in Australian helicopter pilots, in which prevalence of neck pain was a secondary outcome. Although no association was found between back pain and total flying hours, pilots who complained of neck pain in the study had flown significantly more hours than pilots who did not have pain.

Our findings also indicate that neck pain in helicopter pilots may be a consequence of long-term exposure to flying. We believe that the significantly higher number of reported flying hours reported in the previous year by the pilots in the neck pain group compared to the reference group may be a short-term effect, thus further confirming a long-term effect of the total flying hours.

It may be argued that these findings are the consequence of confounding by age, as a significant trend was observed between those reporting regular and continuous neck pain and older age in our data. However, total flying hours logically increased with total career-length and thus with older age (Table I). This fact, along with equivocal reported results about the effect of age on neck pain in the literature, further suggests that it is total flying hours that are associated with flight-related neck pain.

In the Swedish study [3], the use of NVG was reported to be the only flight-related factor indicating an increased risk for neck pain, although this finding was not significant. In a NATO Research and Technology Organization (RTO) report, Greeves and Wickes [15] reported that an increased total number of NVG flying hours was associated with an increased probability of having suffered flight-related neck pain. Helicopter pilots in their study who had flown over 700 hours using NVG had more than an 80% likelihood of developing neck pain, compared to less than 53% for those pilots with fewer than 200 hours flown with NVG. In the current study, total hours flown with NVG was not significantly associated with the prevalence of neck pain. On average, the
pilots in our study had flown 81 hours with NVG. This relatively low number, however, may be insufficient to demonstrate an association between NVG flying hours and the prevalence of neck pain. Hostile missions are increasingly executed in the darkness, and nighttime training operations are therefore becoming more important in the RNLAF and RNLN. The use of NVG will increase, and we may see changes in pain outcomes due to greater use of NVG equipment.

The ergonomic situation when flying a helicopter may play a role in developing neck complaints. Cockpit design, seats, vibration frequencies and helmet-use are factors that differ among helicopter types. Since it is common for pilots of the RNLAF to have flown more than one type of transport helicopter, analyses between single types of helicopter would not have been appropriate. Therefore, the analyses were made among three categories: pilots flying the Lynx helicopter, the RNLAF transport helicopters and the Apache attack helicopter. This classification allowed discrimination among the helmet types used, as well: the alpha 200 (Helmet Integrated Systems LTD), the HGU-56/P (GENTEX) and the Integrated Helmet Unit (Honeywell Minneapolis), respectively. The prevalence of regular or continuous neck pain significantly differed among these groups. However, further analyses revealed that these groups also differed in total flying hours and conclusions should therefore be made with caution (mean (SD) for total flying hours for pilots flying the Lynx helicopter; pilots flying the RNLAF transport helicopters; and pilots flying the Apache were: 1620 (1219), 2203 (1590) and 1298 (896) respectively). However, ergonomic situations, including helmet type and types of helmet-mounted devices, may differ among types of helicopters; these differences should be taken into account when preventive measures are developed.

In addition to flying, there are numerous other activities in a pilot’s job. Several studies have demonstrated the associations between duration of computer work and general job dissatisfaction with neck pain [7;12]. Neither of these factors was found to be associated with neck pain among our sample. This lack of association further suggests a link between flight-specific issues and neck pain in helicopter pilots.

Conclusions and recommendations

The one-year prevalence of any neck pain was 43%, and 20% for regular or continuous neck pain, in Dutch military helicopter pilots; this figure is similar to that for the Dutch non-flying working population. However, because military helicopter pilots are believed to be a healthier-than-average population, this prevalence may indicate a higher risk for neck pain in military helicopter pilots and must be taken seriously. Furthermore, in addition to significant differences in individual and health-related factors (also often reported in the general population), flying hours were significantly higher in pilots with neck pain compared to their colleagues without neck pain. This finding indicates that neck pain in helicopter pilots may be a consequence of long-term exposure to flying. Since reducing flying hours will result in poorly trained helicopter pilots, and further operational demands make reducing flying hours virtually impossible, studies should
be undertaken to determine if ergonomic improvements in cockpit design, seats and helmets would mitigate long-term neck pain incidence. Furthermore, encouragement of specific neck exercises may be a useful prevention strategy, based on previous research in which they reduced complaints in neck pain patients; more research is necessary to demonstrate a preventive effect in this population.
References


Neck pain in military helicopter pilots: Prevalence and associated factors
Differences in physical workload between military helicopter pilots and rear aircrew members

Chapter 5

Marieke Van den Oord, Judith Sluiter, Monique Frings-Dresen

Submitted
Abstract

**Purpose:** Pilots and rear aircrew members perform different tasks when flying helicopters. The aims of the current study were to estimate the one-year prevalence of neck pain in military helicopter rear aircrew members and to compare physical workload between pilots and rear aircrew members.

**Methods:** A survey was completed by almost all available helicopter pilots (n=113) and rear aircrew members (n=61) of the Dutch Defence Helicopter Command. The outcome measures were self-reported neck pain and nine physical load factors that had been associated with work-related neck pain. Differences in the proportions of helicopter pilots and rear aircrew members reporting being often exposed to the particular physical load were assessed with the $\chi^2$ test.

**Results:** For the rear aircrew, the one-year prevalence of neck pain was 62% for any neck pain and 28% for regular or continuous neck pain. Significantly more rear aircrew members than pilots reported being often exposed to manual material handling, performing dynamic movements with their torsos, working in prolonged bent or twisted posture with their torsos or their necks, working with their arms raised and working in awkward postures. Frequent exposure to prolonged sitting and dynamic movements with the neck were equally reported by almost all the pilots and rear aircrew members.

**Conclusion:** Flight related neck pain is prevalent in both military helicopter pilots and rear aircrew members. The exposures to physical load factors that have been associated with neck pain differ between occupations, with more rear aircrew members subject to a variety of physical load factors. These results have implications for preventive strategies for flight-related neck pain.
Differences in physical workload between military helicopter pilots and rear aircrew members

Introduction

Neck pain is an occupational problem in military aviation that may interfere with flying performance and concentration [2;13;14], which makes neck pain both a health and a flight safety concern. In military aviation neck pain is a well-described problem in pilots flying fast jet aircrafts and pilots flying helicopters; two different occupations within military aviation with different job demands and different etiologies of flight-related neck pain [7;9;15;18]. The reported one-year prevalence of neck pain among F-16 pilots fluctuates from 19% to 63% [1;9] and among helicopter pilots from 29% to 57% [2;5;14], depending on the definitions, methodologies and criteria used. Recently, we found a one-year prevalence of 43% of any neck pain and 20% of regular or continuous neck pain among the military helicopter pilots of the Dutch Defence Helicopter Command (DHC) of the Royal Netherlands Air Force [18]. Depending on the type of helicopter, military helicopters are operated not only by the pilots, but also by the rear aircrew members. To better understand the etiology of flight-related neck complaints, it is important to study neck pain in both occupations.

It is generally agreed that the etiology of work-related neck pain in the general population is multi-factorial involving individual, physical and psychosocial factors and can be work-related or non-work-related [4;8]. Work-related factors that have been associated with neck pain among helicopter pilots include flying hours [18] and the use of night vision goggles (NVG) [2]. In the general working population, there is some evidence of several work-related physical risk factors for neck pain including neck postures, arm postures, duration of sitting, twisting or bending of the trunk, hand-arm vibration, awkward postures, work-place design and heavy physical work [4;8].

Helicopter pilots and rear aircrew members perform different tasks in the helicopter. The pilots work in the cockpit and fly the helicopter that, depending on the type and mission, is used to transport troops and cargo, perform search and rescue missions, and provide close combat support for ground troops. The rear aircrew members work in the cabin of the helicopter and their main tasks include troop management, material handling, hoist operation, rescue, surveillance and clearance tasks, and sensor operation. Although pilots and rear aircrew members both have to address specific factors that comes with military helicopter operations such as wearing heavy headgear while performing their tasks, their tasks differ, the work environments within the helicopter (cockpit versus cabin) differ, and consequently the physical loads differ. Because particular physical load factors have been associated with neck pain in different occupations [4;8], we were interested in the differences in exposure to these risk factors between pilots and rear aircrew members.

The aims of the current study were to estimate the self-reported one-year prevalence of neck pain in military rear aircrew of the Dutch Defence Helicopter Command (DHC) and to compare self-reported physical load between helicopter pilots and rear aircrew members.
Methods

Participants
All helicopter squadrons of the DHC were involved in this study. The squadrons are made up of six helicopter types as follows: the ICH-47D Chinook, the AS-532 U2 Cougar, the Agusta-Bell 412, the Alouette III, the Westland SH-14D Lynx helicopter and the AH-64D Apache. A total of 61 military helicopter rear aircrew members (59 men and two women) and 113 pilots (103 men and 10 women) voluntarily completed an anonymous survey. The results of this survey about the prevalence of neck pain and associated factors among the helicopter pilots have been published previously [18]. Descriptive data of the individual characteristics and flight experience of the participants are shown in Table I.

Table I. Descriptive data of individual characteristics and flight experiences of the military helicopter pilots and rear aircrew members.

<table>
<thead>
<tr>
<th></th>
<th>Pilots (n=113)</th>
<th>Rear aircrew (n=61)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>183 (7)</td>
<td>182 (8)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82 (11)</td>
<td>83 (9)</td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
<td>24.4 (2.5)</td>
<td>25.0 (2.0)</td>
</tr>
<tr>
<td>Total flying hours</td>
<td>1836 (1407)</td>
<td>1625 (1300)</td>
</tr>
<tr>
<td>Flying hours in previous year</td>
<td>164 (68)</td>
<td>196 (73)</td>
</tr>
<tr>
<td>NVG hours</td>
<td>81 (121)</td>
<td>107 (122)</td>
</tr>
</tbody>
</table>

Procedures
The helicopter squadrons were introduced to the study by an oral briefing and written information was provided to all the pilots and rear aircrew members unless they were on deployment. Each squadron was then visited on three to four consecutive days, depending on the presence of the pilots (November 2006-March 2008). Only crew members who were on deployment, or on sick- or holiday leave were not reached and were excluded from recruitment. Almost all the pilots and rear aircrew members present on these days participated (96% response rate) and gave their written informed consent. Ethical approval for the study was waived because the questionnaires were anonymous and contained no material subject to privacy constraints.

The questionnaire was based on the standardized “Dutch Musculoskeletal Questionnaire” (DMQ) [12] and contained additional questions about flight-related issues, including flying hours and experience. Participants reported to a member of the research team who was housed in or near the squadron building. The researcher gave
instructions to each participant about the process of filling out the questionnaire. The questionnaires were completed electronically, using Microsoft Office Access 2003 and typically time needed to complete the questionnaire was 20 minutes. Selected items from this questionnaire were used to answer the specific research questions of the current study.

Work-related physical load
The work-related physical load part of the questionnaire consisted of twenty yes/no questions. Twelve questions were considered to be relevant for this study, based on earlier research that identified specific physical risk factors for work-related neck pain [4;8]. These questions were as follows:

During your job, do you often:

1. lift/pull/push loads of more than 5 kg
2. lift/pull/push loads of more than 20 kg
3. bend or twist your torso
4. bend or twist your neck
5. make repetitive movements with your torso
6. make repetitive movements with your neck
7. work in a prolonged bent or twisted posture with your torso
8. work in a prolonged bent or twisted posture with your neck
9. work with your arms raised
10. work in awkward postures
11. work in the same position/posture
12. sit for prolonged durations

Outcome measures and analyses
The outcome measure for the first research question of the study was self-reported neck pain. Neck pain was defined in the questionnaire as any pain, including aches and discomfort in the previous 12 months; in addition, a diagram was used to illustrate and define the specific body region. There were four possible choices: never, occasional, regular or continuous pain.

To answer the second research question of the study, the questions assessing physical loads of the same order were combined into one outcome measure in the analyses. Participants answering YES on one of these questions were considered in the YES-group for this outcome measure, resulting in the following nine outcome measures: often exposure to material handling (question 1 and 2), dynamic movements with the torso (question 3 and 5), dynamic movements with the neck (question 4 and 6), prolonged bent or twisted posture with the torso (question 7), prolonged bent or twisted posture with the neck (question 8), raised arms (question 9), awkward postures (question 10), prolonged the same position/posture (question 11) and prolonged sitting (question 12).
Statistical analyses were performed with SPSS 18.0. Differences in the proportions of helicopter pilots and rear aircrew reporting being exposed often to the particular physical load were assessed with the $\chi^2$ test. When the assumption of a minimal expected number of 5 in each of the four cells was violated, Fisher’s exact test was used to obtain the p-value. A p-value of < 0.01 was considered to be statistically significant.

Results

The one-year prevalence of self-reported neck pain of the rear aircrew was 62% (n=38/61) for any neck pain, and 28% (n=17/61) for regular or continuous neck pain. All but one of the rear aircrew members reporting regular or continuous neck pain attributed their neck pain to flying, and 77% indicated that their complaints started during flights.

The self-reported physical load of the pilots and rear aircrew are shown in Table II. Significantly more rear aircrew members than pilots reported often being exposed to manual material handling ($\chi^2 = 80.3$, 1 d.f., p< 0.000), performing dynamic movements with their torsos during work ($\chi^2 = 28.7$, 1 d.f., p< 0.000), working in a prolonged bent or twisted posture with their torsos ($\chi^2 = 32.1$, 1 d.f., p< 0.000) and their necks ($\chi^2 = 19.3$, 1 d.f., p< 0.000), working with their arms raised ($\chi^2 = 11.5$, 1 d.f., p= 0.001) and working in awkward postures ($\chi^2 = 57.1$, 1 d.f., p< 0.000). Significantly more pilots than rear aircrew members reported often being exposed to prolonged work in the same position/posture during their job ($\chi^2 = 10.9$, 1 d.f., p= 0.001). Almost all pilots (97%) and rear aircrew (100%) reported often making dynamic movements with their necks during their job. Almost all pilots (96%) reported being exposed to prolonged sitting, but this proportion was not significantly higher than the proportion rear aircrew members (85%) reporting being exposed to prolonged sitting (p=0.037).

Table II. Percentage of the pilots and rear aircrew members often exposed to the different aspects of physical workload.

<table>
<thead>
<tr>
<th></th>
<th>Pilots (n=113)</th>
<th>Rear aircrew (n=61)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual material handling</td>
<td>24%</td>
<td>95% *</td>
</tr>
<tr>
<td>Dynamic movements with torso</td>
<td>61%</td>
<td>98% *</td>
</tr>
<tr>
<td>Dynamic movements with neck</td>
<td>97%</td>
<td>100%</td>
</tr>
<tr>
<td>Prolonged bent or twisted posture with torso</td>
<td>43%</td>
<td>87% *</td>
</tr>
<tr>
<td>Prolonged bent or twisted posture with neck</td>
<td>56%</td>
<td>89% *</td>
</tr>
<tr>
<td>Raised arms</td>
<td>15%</td>
<td>38% *</td>
</tr>
<tr>
<td>Awkward postures</td>
<td>34%</td>
<td>93% *</td>
</tr>
<tr>
<td>Prolong same position/posture</td>
<td>91% *</td>
<td>72%</td>
</tr>
<tr>
<td>Prolonged sitting</td>
<td>96%</td>
<td>85%</td>
</tr>
</tbody>
</table>

* Significantly higher proportion compared to the other occupation, p<0.01


Discussion

Main results and comparison with the literature

Based on the levels of the prevalence rates found (>25%), and the statements by almost all the aircrew members indicating that neck pain was flight-related, the results of the current study suggest that for the rear aircrew members, neck pain is a work-related problem. Considering the second aim of this study, the results suggest that the exposure of the pilots and rear aircrew members to physical load factors that have been associated with neck pain differ between occupations. The rear aircrew members are more often exposed to manual material handling, making dynamic movements with their torsos, working in prolonged bent or twisted postures with their torsos and necks and working with raised arms compared to the pilots, whereas the helicopter pilots more often experience prolonged body positions/postures compared to the rear aircrew. Often exposure to prolonged sitting and dynamic movements with the neck were reported equally by almost all the pilots and rear aircrew members.

The overall one-year prevalence of neck pain among the military helicopter rear aircrew members was 62% for any neck pain and 28% for regular and continuous neck pain. These year prevalence rates tend to be higher compared to those (43% of any and 20% of regular and continuous neck pain) among the helicopter pilots of the Dutch Defence Helicopter Command (DHC) [18]. Higher prevalence rates of neck pain in rear aircrew compared to pilots were reported in British military helicopter crew, for whom the career prevalence of flight-related neck pain was 57% for the pilots and 71% for the rear aircrew [11]. Non-flying Dutch workers reported a one-year prevalence of 55% for any neck pain and 22% for regular and continuous neck pain [17], which are approximately the same as those for the rear aircrew of the DHC. However, the rear aircrew members of the DHC have to meet medical and physical standards when they enter the defence organization and are medically and physically checked annually; thus rear aircrew members are assumed to be in a better physical condition compared to the non-flying working population. These results indicate a higher risk for neck pain among the rear aircrew than the non-flying working population.

The second aim of this study was to compare the self-reported exposure to physical load factors that have been associated with work related neck pain between the helicopter pilots and rear aircrew members. Here, a number of results are noted. The vast majority of the rear aircrew members report being often exposed to almost all of these physical load factors. Within the pilot group, a convincing majority reported being often exposed only to prolonged the same posture, to prolonged sitting and to performing dynamic movements with the neck. This indicates that the rear aircrew is exposed to a greater variety of physical loads. Because their tasks are more varied compared to the tasks of the pilots, this is not surprising.

A second finding is that almost all the pilots and all rear aircrew members report being often exposed to dynamic movements with their neck. In addition, a small majority of
the helicopter pilots and a vast majority of the rear aircrew members reported often exposure to prolonged bent or twisted postures of their neck. Recently, Forde et al. [10] found that the percentage of time spent in a non-neutral neck position was 48% during day-time flights and 87% during night-time flight for pilots. We could not find any studies that investigated the neck postures of rear aircrew. Several studies have shown that time spent in a non-neutral position is positively associated with neck pain [3;4]. As Forde et al. [10] suggested, it would be interesting to measure the cumulative neck load that pilots and rear aircrew members are exposed to, because both helicopter pilots and rear aircrew members wear heavy headgear, which increases moment loading on the neck compared to a non-neutral posture without headgear. Cumulative loading addresses loading force a joint experiences over a particular period of time and is influenced by a combination of posture, repetition, duration and force; furthermore cumulative loading has been found to be a risk factor in pain associated with the lower spine [6], but has not been investigated in relation to neck pain.

**Implications for prevention**

The results of the current study show that rear aircrew and pilots are two occupations flying in the same helicopter but exposed to a different variety of physical load factors. In both professions work-related neck pain is prevalent. Interventions aiming to prevent this flight-related neck pain may therefore be job specific or could focus on the similarities of the two occupations, resulting in an intervention that benefits both occupations.

Is it possible to reduce the exposure to the flight related physical workload for both the rear aircrew members and the pilots? At the organizational level, reduction in exposure might be accomplished by reducing flying hours; however, considering the operational demands and the maintenance of the flight skills of the crew, this reduction is not feasible.

The results of the current study reveal that the pilots and rear aircrew are both often exposed to dynamic movements with their neck. At the technical level, an intervention that might be profitable for both the rear aircrew and pilots, could involve modification to their headgear. Pilots and rear aircrew wear heavy head worn equipment as a flight helmet and mounted devices such as NVG’s, head-up displays and counterweights. Recently we showed that modifications of this equipments realized by optimizing the helmet fit, resulted in less neck load and neck pain experienced by the pilots and rear aircrew during night flights [19]. In a qualitative study [20], we identified three factors that directly related to the experienced neck load by the aircrew during flight: the type of flight operations, the weight of the headgear and the weight distribution of the headgear. Because of the operational mission of the DHC, changes in the type of flight operations are not feasible. Thuresson [16] revealed that both neck postures and different configurations of headgear caused measurable changes in muscle activity and induced load. These results and the fact that both the pilots and rear aircrew members
in the current study reported being often exposed to dynamic neck movements, indicate that additional modifications to the headgear related to its weight and weight distribution, could impact the cumulative load as noted earlier in this discussion for both the rear aircrew members and pilots.

Another intervention both the rear aircrew members and pilots could profit from is to provide information about the work-related physical load factors and physically demanding work postures and their relation to symptoms. This information can improve their awareness, lead to behavioral changes, and might result in less demanding postures and activities. The information provided to the crew should be based on the physical loads they are exposed to and therefore should be profession-specific for both the rear aircrew members and pilots. Nevertheless, the evidence for the effectiveness of these types of educational interventions for neck pain is unknown.

**Conclusion**

Neck pain is a prevalent flight related problem in military helicopter crew. We observed differences in the self-reported exposures to physical load between rear aircrew and pilots; more rear aircrew members than pilots were exposed to manual material handling, dynamic movements with their torsos, prolonged bent or twisted posture with their necks and torsos, work with raised arms and awkward postures. More pilots than rear aircrew members reported being exposed to prolonged the same position/posture, while almost all the pilots and rear aircrew members were exposed to dynamic movements with their necks and prolonged sitting. These results provide information about the physical workload the pilots and rear aircrew are exposed to that have been associated with neck pain in other occupations and have implications for preventive strategies for flight-related neck pain.
References


Prevention of flight-related neck pain in military aircrew
Neck strength, position sense, and motion in military helicopter crew with and without neck pain

Chapter 6
Abstract

**Introduction:** Neck pain in military helicopter pilots and rear aircrew is an occupational health problem that may interfere with flying performance. The aim of the present study was to investigate possible differences in the physical abilities of the cervical spines of helicopter pilots and rear aircrew with and without neck pain in the previous year.

**Methods:** The study included 61 male helicopter pilots and 22 rear aircrew without neck pain (Sx-) and 17 pilots and 17 rear aircrew with neck pain (Sx+). Active cervical range of motion (flexion-extension, right-left rotation, and right-left lateral flexion), neck position sense (reposition error back to neutral and defined positions after submaximal cervical movement) and maximum isometric neck muscle strength (flexion, extension and right and left lateral flexion) were measured. Two-way factorial analyses of variance were performed, in which the fixed factors were occupation (pilot or rear aircrew) and neck pain state (Sx+ or Sx-).

**Results:** On average, there was a trend toward lower values in strength (extension: 55(19)Nm vs. 58(20)Nm; flexion 22(8)Nm vs. 24(12)Nm) and smaller cervical range of motion (flexion-extension: 132(19)° vs. 137(15)°; rotation: 156(14)° vs. 160(14)°) in the total Sx+ crew, compared to their Sx- colleagues. However, the two-way factorial ANOVA revealed neither significant main effects nor significant interaction effects in any of the measured physical abilities.

**Conclusion:** The results suggest that having experienced neck pain was not significantly associated with differences in the physical abilities of the cervical spines of helicopter crew, as assessed in this study.
Introduction

Neck pain in military pilots is an occupational health problem that may interfere with their flying performance [17;22]. Consequently, this can lead to unsafe situations. Obviously, flight-related neck pain should be prevented when possible, and the etiology and mechanism that play a part in the development, occurrence and perpetuation of flight-related neck pain should first be identified [26].

Neck pain in fighter pilots is a well discussed issue, but only recent studies have recognized neck pain among helicopter pilots as a significant aero-medical problem, with reported 3- to 12-month prevalences ranging from 29% to 57% [1;6;22]. Although the etiology of flight-related neck pain in helicopter pilots is still the subject of research, specific ergonomic situations when flying a helicopter, namely unfavorable neck load caused by 1) static neck and body positions, 2) whole body vibration (WBV) and 3) heavy head-worn equipment, have been suggested as risk factors [23].

While the prevalence and etiology of neck pain in military jet and helicopter pilots has been the subject of research, cervical complaints of the non-piloting aircrew have been largely ignored up to now. However, military aircrew sitting in the rear of the helicopter deal with the same three suggested risk factors for neck pain as helicopter pilots. The main tasks of military rear aircrew are troop management, material handling, surveillance, and clearance tasks. These tasks require different body and head postures, including sitting forward, kneeling, standing positions with the trunk flexed and rotated and the head out of window and lying positions with the head outside the hatch for hooking and hoisting tasks [15]. When flying in darkness, not only the pilots but also the rear aircrew use night vision goggles, increasing the mass the head must bear, and perform the same tasks as mentioned above. Although in-flight studies on postures and head movements in helicopter pilots and rear aircrew are scarce, the important difference between these two occupations seems to be the rather static, unfavorable neck and body positions for helicopter pilots, while the rear aircrew have to deal with more extreme, but more variable head and body positions. Thuresson [23] revealed that all three suggested risk factors for flight-related neck pain in helicopter pilots (neck and body position, WBV and heavy, head-worn equipment) caused measurable changes in muscle activity, induced load and seat-to-head transmissibility; however, neck and body position caused the highest response.

Despite the same work environment and selection criteria for each specific occupation, some pilots and rear aircrew develop neck pain, while others do not. To understand neck pain in military helicopter pilots and rear aircrew, it is interesting to quantify neck muscle function in these workers, since neck muscle function is essential for support and stabilization of the head on the cervical spine. For the purposes of prevention and intervention and, importantly, to keep the crew on active flying duty, early detection of cervical functional loss may be important. This may be especially true because pain, cervical dysfunction and control of movement can interact negatively with each other [9].
In order to provide a proper preventive training program for military helicopter pilots and rear aircrew, a battery of tests was used in the current study for assessing the physical abilities of the cervical spine. The main purpose of the current study was to investigate the physical abilities of the neck in helicopter pilots and rear aircrew with neck pain and compare them to pilots and aircrew without neck pain. We examined 1) active cervical range of motion, 2) neck position sense and 3) neck muscle strength.

Based on earlier research in non-flying populations [7;16] and in military pilots [2;3], we hypothesized that pilots and rear aircrew who experienced neck pain in the previous 12 months would have a smaller cervical range of motion, a greater reposition error (the outcome measurement of neck position sense testing) and lower muscle strength compared to pilots and rear aircrew without neck pain. Based on the differences in occupational postures causing different neck loading and requiring different abilities, we hypothesized more specifically that muscle strength and cervical range would be affected more greatly in rear aircrew, while the more static postures used by pilots would lead to a higher relative impairment of neck position sense.

Methods

Subjects and Procedures
The current study was a collaboration of the Royal Netherlands Air Force (RNLAF) and the Belgian Defense. A battery of tests was developed for the assessment of the physical abilities of the cervical spine by the Medical Component of the Belgian Defense. The results of these tests with Dutch and Belgian F-16 pilots have been published previously [10]. The battery of tests consisted of a test to measure cervical mobility, a test to assess neck position sense and a cervical strength test. All tests were performed on the same day, and participating pilots and rear aircrew had not flown on the day of the tests. Muscular strength was always measured last, to avoid the influence of muscular fatigue on the other tests. The pilots and rear aircrew filled in standardized questionnaires to record their ages, weights, heights, flying hours and experience and neck pain during the preceding 12 months. Each assessment had a permanent examiner, who was blinded to the subject history of neck pain.

Squadrons were verbally briefed about the study by the research team, and all pilots and rear aircrew received written information and gave written, informed consent. Next, each squadron was visited by the research team on three to four consecutive days between November 2006 and March 2008, depending on the availability of the pilots and aircrew. The intention was to test all helicopter pilots and rear aircrew of the RNLAF and RNLN and only the crew who were on deployment, sick- or holiday leave were not reached this way. Almost all pilots and rear aircrew present participated (response rate 96%). Pilots and rear aircrew were excluded if they had not been on flying duty during the previous year. Ethical approval was obtained from the Ethical Research Committee.
Neck strength, position sense, and motion in military helicopter crew with and without neck pain

of Ghent University, and the Ethical Research Committee of the University Medical Center of Utrecht agreed that no additional insurance was needed for participants. A total of 113 helicopter pilots (103 males and 10 females) and 61 rear aircrew (59 males and 2 females) from the RNLAF and the RNLN participated. They flew six helicopter types: the ICH-47D Chinook, the AS-532 U2 Cougar, the Agusta-Bell 412, the Alouette, the Westland SH-14D Lynx helicopter and the AH-64D Apache. For reasons explained below, the female pilots and aircrew and those who reported only occasional neck pain in the previous 12 months were excluded from analysis. This led to the inclusion of 17 pilots with and 61 pilots without neck pain, 17 rear aircrew with and 22 rear aircrew without neck pain. Total means (SD) for height, weight and body mass index were 183.5 (6.9), 83.0 (9.7) and 24.6 (2.3), respectively, and not significantly different between the four groups. Of the total group, 36% was aged <30 years, 38% between 30-40 years and 26% between 40 and 55 years. In the pilot group, the Chi-Square test revealed a significant linear-by-linear association between neck pain and higher age (p=0.01). Total flying hours and flying hours the previous 12 months were 2830(1642) and 197(86) respectively for the pilots with neck pain and 1680(1265) and 152 (65) for the pilots without neck pain, and 1553(912) and 206(67) respectively for the rear aircrew with neck pain and 1537(1476) and 226(80) for the rear aircrew without neck pain. Within the pilot group, the Mann-Whitney U test revealed that these differences were significant for the total flying hours (p=0.008) as well as the flying hours in the previous 12 months (p=0.04). There were no significant differences in age and flying hours within the rear aircrew group.

Neck Pain
Neck pain was defined as any pain, including aches and discomfort, in the previous 12 months, and a diagram was used to illustrate and define the specific body region. Within each occupational group (pilots or rear aircrew), subjects were divided into a symptomatic group (Sx+) (those reporting regular or continuous neck pain) and an asymptomatic group (Sx-) (without neck pain), based on their answers to the four possible responses about neck pain on the questionnaire (never, occasional, regular and continuous). For the purposes of this study, pilots and rear aircrew who reported occasional neck pain were excluded from analysis to create as much contrast as possible between groups.

Cervical Range of Motion
Active cervical range of motion (CROM) was measured with a three-dimensional motion analyzer, Zebris CMS20, WinSpine version 1.79 (Zebris Medizintechnik GmbH, Isny, Germany). Measurement was based on determination of the spatial coordinates of the ultrasound (US) transmitters by a fixed system of three microphones which was positioned at a special stand close by. Specially designed headgear (adjustable to adapt to individual head sizes), on which a series of three miniature US transmitters
were attached, was fixed to the subject’s head. For isolating cervical spine movements from the rest of the spine, a thoracic belt (velcro bands adjustable to the individual torso) attached to a series of three miniature US transmitters, was fixed to the subject’s torso, serving as a reference.

Each subject was seated in an upright position on a stool without a backrest. The subject’s hands were placed on his thighs, and hips and knees were bent at 90°. To be sure that the subject’s starting position between moving in different directions was the same, a narrow mirror was placed so that the subject was able to see his own eyes in this position. The device was calibrated before the start of the first movement. After each movement, the subject was asked to look at his eyes in the mirror. The maximal full CROM was measured for flexion-extension, right-left rotation and right-left lateral flexion. Each measurement consisted of three repetitions for each movement. For each direction, the mean of the three repetitions was recorded. The reproducibility of the CROM test is described by Cagnie et al. [7] and was shown to be high for all directions. Intraclass correlation coefficients (ICCs) ranged from 0.92 to 0.94 for inter-rater reliability and from 0.80 to 0.87 for intra-rater reliability.

**Neck Position Sense**

The three-dimensional motion analyzer Zebris CMS20, using Windata version 2.20 (Zebris Medizinetechnik GmbH, Isny, Germany), was used to measure neck position sense. The subject was seated in an upright position on a stool without a backrest. The subject’s hands were placed on his thighs; hips and knees were bent 90°. The subject was blindfolded for this test. The point of departure was the neutral neck position defined by each subject. The test consisted of two parts. In the first part, the subject was instructed to return to his own neutral position after an active sub-maximum range cervical flexion-extension and right and left rotation. In the second part, the subject was asked to return to a position defined by the researcher (30° right or left rotation). For the first part, the absolute reposition error (RPE) was calculated in the sagittal plane and transversal plane, as a mean of 10 repetitions. For the second part, the absolute RPE was calculated in the transversal plane for right and left rotation, as a mean of five repetitions in each direction. The test’s reproducibility was confirmed by analysis of 15 healthy, civilian volunteers. The ICC for the reposition error to the neutral position was 0.87 for inter-rater reliability and 0.72 for intra-rater reliability. For the absolute RPE in the repeated-matching test to 30° rotation, the ICC for the inter-rater reliability was 0.67 and 0.61 for the intra-rater reliability (De Loose V, Cagnie B. Unpublished data; 2006).

**Strength**

Maximum isometric neck muscle strength was measured with a David F-140 device (David International, Ltd., Germany). Each subject was seated in an upright position with outstretched legs, with only the heels touching the floor, and arms relaxed against
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The seat height, motion axis of C7-T1 (in line with the axis of the moving arm of the testing unit) and chest support were adjusted for each subject. The subject performed a standardized warming-up for the neck and shoulders before any measurements were taken. Isometric tests were then performed in four directions: flexion, extension and left and right lateral flexion. The same order of testing was used for all subjects. Three maximum voluntary isometric contractions (MVCs) were executed in each direction. The subject was encouraged to press his head against the resistance pad with increasing force up to a maximum voluntary contraction of 6 seconds. Within one series, there were 30 seconds of rest, and in between the tests of different directions there was a rest period of 3 minutes. The highest peak value (Nm) was used for further analysis. The reproducibility was confirmed by tests on 15 healthy, civilian volunteers. The ICC ranged from 0.94 to 0.95 for the peak value (Nm) of the different strength tests for both the inter- and intra-rater reliability (De Loose V, Cagnie B. Unpublished data; 2006).

Analyses

The number of female pilots and rear aircrew was small and proportionally unequal in the four groups. Since females possess lower cervical strength [12], and inconsistent and limited results have been reported on the effect of gender on neck mobility and neck position sense [8;11;13], it was decided to exclude the female subjects from analysis. Statistical analyses were performed with the SPSS 16.0 software package (SPSS Inc., Chicago, IL). The dependent variables were MVC, CROM, and RPE. Means and standard deviations were used to describe the data. Two-way factorial analysis of variance (ANOVA) was used, in which the fixed factors were occupation (pilot or rear aircrew) and neck pain state (Sx+ or Sx-). When significant interactions were found, simple effects (the effect of one independent variable at the individual level of the other independent variable) were examined with simple effects analysis [14]. Since every dependent variable was analyzed separately, an adjusted p value of 0.01 was considered statistically significant in all tests.

Results

The results for the helicopter aircrew with neck pain (Sx+) and crew without neck pain (Sx-) within each occupation (pilot and rear aircrew) are summarized in Table I. For the extensors and flexors, the total Sx+ crew scored lower mean values (55 (19) Nm and 22 (8) Nm, respectively) compared to the Sx- crew (58 (20) Nm and 24 (12) Nm, respectively). Within each occupation, the Sx+ helicopter pilots scored lower mean values (51 (20) Nm and 22 (9) Nm, respectively) compared to their Sx- colleagues (58 (18) Nm and 24 (12) Nm, respectively), and the Sx+ rear aircrew scored equal values for the extensors and lower values for the flexors compared to the Sx- rear aircrew.
However, the two-way factorial ANOVA revealed neither significant main effects (neck pain state; $F_{1,110} = 0.7$, $p=0.4$ and $F_{1,110} = 0.3$, $p=0.6$ for the extensors and flexors, respectively) nor significant interaction effects (neck pain state x occupation; $F_{1,110} = 0.7$, $p=0.4$ and $F_{1,110} = 0.02$, $p=0.9$, for the extensors and flexors, respectively). Also, for the right and left lateral flexion muscles, the Sx+ crew scored lower mean values ($29(19)$ Nm and $30(20)$Nm, respectively) compared to the Sx- crew ($31(20)$Nm and $32(20)$Nm, respectively) and within each occupation these differences were more obvious in the rear aircrew. However, these differences were not significant, since there were neither significant main effects (neck pain state; $F_{1,110} = 0.8$, $p=0.4$ and $F_{1,110} = 0.3$, $p=0.6$ for the right and left lateral flexion muscles, respectively) nor significant interaction effects for both variables (neck pain state x occupation; $F_{1,110} = 0.3$, $p=0.6$ and $F_{1,110} = 0.05$, $p=0.8$ for the right and left lateral flexion muscles, respectively).

For the neck position sense variables, greater reposition errors indicate lower accuracy in bringing the head back to a neutral or defined position. No significant main effects or interaction effects were found in any of the proprioception variables.

For cervical range of motion in the sagittal plane, the Sx+ crew showed a smaller CROM compared to the Sx- crew ($132(19)^\circ$ and $137(15)^\circ$, respectively) but no significant main (neck pain state; $F_{1,113} = 2.1$, $p=0.1$) or interaction effects were revealed (neck pain state x occupation; $F_{1,113} = 0.8$, $p=0.4$). Furthermore, in the transversal plane, the total Sx+ crew with neck pain showed a smaller CROM ($156(14)^\circ$) compared to their Sx- colleagues ($160(14)^\circ$), but within each occupation this difference was only shown in the pilots. However, in this variable, as well, neither main (neck pain state; $F_{1,111} = 1.0$, $p=0.3$) nor interaction effects were found (neck pain state x occupation; $F_{1,111} = 0.9$, $p=0.3$).

**Discussion**

Neck function in helicopter pilots and rear aircrew was examined by measuring the active cervical range of motion, neck position sense and neck muscle strength. The results did not support our hypotheses that neck function would significantly be altered in helicopter pilots and rear aircrew with neck pain compared to the pilots and aircrew without neck pain, and that the possible differences between neck pain and healthy subjects would be significantly different for pilots compared to rear aircrew. These results suggest that, with the tests used in this study, deficits in cervical physical abilities because of neck pain cannot be detected. Moreover, they suggest that, based on these tests, military helicopter pilots and rear aircrew cannot be advised on an individualized preventative training program.
<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Helicopter Pilot Sx+</th>
<th>Helicopter Pilot Sx-</th>
<th>Rear Aircrew Sx+</th>
<th>Rear Aircrew Sx-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck Muscle Strength (Nm)</td>
<td>n=16</td>
<td>n=61</td>
<td>n=15</td>
<td>n=22</td>
</tr>
<tr>
<td>Extensors</td>
<td>51 (20)</td>
<td>58 (18)</td>
<td>60 (18)</td>
<td>60 (23)</td>
</tr>
<tr>
<td>Flexors</td>
<td>22 (9)</td>
<td>24 (12)</td>
<td>21 (8)</td>
<td>22 (10)</td>
</tr>
<tr>
<td>Right lateral flexion</td>
<td>28 (18)</td>
<td>30 (18)</td>
<td>29 (20)</td>
<td>35 (24)</td>
</tr>
<tr>
<td>Left lateral flexion</td>
<td>29 (19)</td>
<td>30 (18)</td>
<td>32 (22)</td>
<td>36 (25)</td>
</tr>
<tr>
<td>Neck Position Sense (°)</td>
<td>n=17</td>
<td>n=61</td>
<td>n=17</td>
<td>n=22</td>
</tr>
<tr>
<td>RPE* sagittal plane after submaximal flexion-extension</td>
<td>2.8 (1.0)</td>
<td>3.1 (1.2)</td>
<td>3.3 (1.4)</td>
<td>3.0 (0.8)</td>
</tr>
<tr>
<td>RPE transversal plane after submaximal rotation</td>
<td>1.9 (0.6)</td>
<td>1.8 (0.6)</td>
<td>2.1 (0.8)</td>
<td>2.1 (0.7)</td>
</tr>
<tr>
<td>RPE transversal plane after right 30° rotation</td>
<td>2.5 (1.1)</td>
<td>2.8 (1.5)</td>
<td>2.8 (1.9)</td>
<td>3.0 (1.3)</td>
</tr>
<tr>
<td>RPE transversal plane after left 30° rotation</td>
<td>2.7 (1.8)</td>
<td>2.6 (1.5)</td>
<td>3.0 (1.2)</td>
<td>2.5 (1.0)</td>
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<tr>
<td>Cervical Range of Motion (°)</td>
<td>n=17</td>
<td>n=61</td>
<td>n=17</td>
<td>n=22</td>
</tr>
<tr>
<td>Sagittal plane</td>
<td>130 (18)</td>
<td>138 (15)</td>
<td>134 (17)</td>
<td>136 (16)</td>
</tr>
<tr>
<td>Frontal plane</td>
<td>82 (15)</td>
<td>82 (15)</td>
<td>83 (15)</td>
<td>83 (14)</td>
</tr>
<tr>
<td>Transversal plane</td>
<td>154 (12)</td>
<td>160 (14)</td>
<td>158 (16)</td>
<td>158 (16)</td>
</tr>
</tbody>
</table>

*RPE=reposition error
Interestingly, the results for the neck strength variables and range of motion variables were always higher in the pilots and aircrew without neck pain, and, on average, there was a trend toward lower values in strength and cervical range of motion in the pilots and aircrew with neck pain, compared to their colleagues without pain. While interpreting the results of this study, some considerations should be taken into account, and the results should be viewed within the limitations of the study as it was performed. First, the results may depend on the definition of neck pain, which here was considered to be any pain, including aches and discomfort, during the previous 12 months. In terms of frequency, the pilots and rear aircrew could report their pain as occurring never, occasionally, regularly or continuously. The division of pilots and rear aircrew into subjects without neck pain and neck pain subjects was based on these self-reports and, thus, relied on the memory of the subjects over a period of 12 months. This problem could have been avoided by use of a prospective design, for example, by having the pilots and aircrew keep “neck pain diaries”, resulting in a more reliable assessment of neck pain in pilots and aircrew. By excluding the pilots and rear aircrew who reported occasional neck pain and, thus, only including the pilots and aircrew with regular or continuous neck pain in the neck pain group, we tried to create as much contrast as possible between the subjects without neck pain and neck pain subjects. Furthermore, by only including the pilots and crew with regular or continuous neck pain, we tried to ensure that these subjects could truly be considered cases of neck pain, as compared to those who reported only occasionally neck pain.

We assessed the physical abilities of the necks of the military helicopter pilots and aircrew by measuring strength, mobility and position sense. These three measures are often used in the practice of civilian physiotherapy. A limitation of the current study, however, is that we did not monitor flying ability, in-flight postures or head movements. It would have been preferable to test physical abilities more applicable to in-flight abilities. Muscle fatigue or endurance was not assessed, for example, although either might play an important role in flight-related neck pain. Helicopter flights of 6 to 8 hours are no longer the exception in the RNLAF or RNLN. In line with Ang et al. [2], we propose that muscle activity associated with flying a helicopter may be generally lower than with flying high Gz-aircrafts. However, dealing with the loading factors for hours probably causes muscle fatigue over time. Because of practical considerations, and the lack of good methods to measure muscle fatigue that would also fit in our test-battery setting without the risk of sore muscles the next day (pilots and crew were to be able to fly directly after the test and the next day), we decided not to measure cervical muscle fatigue. It would be interesting, however, to measure in-flight cervical muscle fatigue as an extra functional measure in future studies.

The strength of the current study is that, by visiting the different squadrons with the battery of tests, more than 75% of all Dutch military helicopter pilots and almost 80% of rear aircrew were reached, and almost all participated. This makes the present sample highly representative of the helicopter pilot and rear aircrew populations of the
Neck strength, position sense, and motion in military helicopter crew with and without neck pain

RNLAF and RNLN. Furthermore, to the best of our knowledge, this is the first study that measured neck function in rear aircrew, while neck pain is a prevalent complaint in this population [25].

In the present study, no differences were observed in neck position sense between pilots and aircrew without neck pain and pilots and aircrew with neck pain, nor was there any difference between the pilots and rear aircrew. Several studies have observed greater reposition errors in subjects with cervical pathology [16;19]. However, other studies did not observe any differences in neck position sense accuracy between neck pain patients and healthy individuals [5;20]. As suggested by Armstrong et al. [4], impaired position sense might depend on the severity of the complaints and the magnitude of problems with daily functioning [21;24]. Our pilots and rear aircrew were still on active flying duty, and, thus, their functioning might still have been on a reasonable level.

In the present study, the results for the neck strength variables followed the same pattern, which consisted of a downward trend from participants without neck pain to neck pain subjects, but the differences were not significant. The largest difference within the strength values was observed in the extensors of the pilots with neck pain compared to the pilots without pain, while the aircrew with and without neck pain scored similar values. We did not measure left- and right rotation strength, which would have provided us more information about the strength status. However with the device used for measuring strength (David F-140) it is not possible to measure rotation strength. We used this device because we have quite some experience with it and good reproducibility data. The results do not confirm our expectations, because we hypothesized that possible differences in strength between the neck pain group and the group without neck pain would be greatest for the rear aircrew. This hypothesis was based on the assumption that rear aircrew would be exposed to greater peak loads on the cervical musculature, as compared to pilots. Aircrew with lower maximum strength might develop neck complaints because their strength capacity would not be sufficient to deal with the high peak loads. However, the neck loads that rear aircrew and pilots were exposed to were not examined in the current study, and research about the actual in-flight neck loads in helicopter pilots and rear aircrew is scarce. Ang et al. [2] measured neck strength in military helicopter and fighter pilots. They hypothesized that, because fighter pilots are exposed to higher peak loads (caused by +Gz forces) compared to helicopter pilots, neck strength values would be altered in fighter pilots with neck pain compared to their colleagues without neck pain, while this would not be the case for helicopter pilots. Indeed, they found their hypothesis to be true, but the cervical demands on fighter pilots may not be comparable to those on rear helicopter aircrew.

We should also take into consideration that the pilots as well as the rear aircrew population of the RNLAF and RNLN represented a pre-selected population and had to meet medical and physical standards before they started their jobs. Peolson et al. [18] measured the strength of the cervical extensors in healthy employed men with the same
equipment and in a similar way as in the current study. They observed an average of 42 Nm (CI: 40-44 Nm) in that study, which is considerably lower than the overall observed mean of 58 Nm in our pilots and aircrew. This suggests either that the military pilots and aircrew already have good genetically defined physical capacities (aircrew self-select to military/aviation service and are screened to eliminate individuals with potentially disqualifying conditions) or that the neck load exposure in flight has a training effect and makes them stronger. Either explanation points to a situation where extra strength training might not result in the desirable effect, as suggested by others [27]. The cervical strength in our population might have been sufficient to deal with the typical in-flight cervical load. Furthermore, since none of the aircrew had neck pain severe enough to keep them from work for a longer period, there might be a healthy worker effect in play. Caution should be taken, however, to extrapolate general conclusions to individuals, since the variation in the cervical strength values was rather high.

The CROM results showed no significant differences between pilots and aircrew with neck pain and their colleagues without pain, nor was there any effect of occupation. However, in line with the cervical strength results, the results for the subjects without pain were always higher than the results for the neck pain subjects, and a trend of smaller CROM values in the sagittal and transversal planes was seen for the helicopter pilots with neck pain. Reduced range of motion in the sagittal and transversal planes has been reported in other neck pain populations [5,7] and in military helicopter pilots [3]. In this latter study, however, the authors differentiated between helicopter pilots with acute neck pain and subacute neck pain, and the pilots with subacute neck pain did not demonstrate lower CROM values in any plane when compared to pilots without neck pain. In our study, we did not differentiate between acute and subacute neck pain, and this might be the reason that we did not find any significant differences. However, post hoc we made a comparison of the pilots and aircrew with prior neck pain and the pilots and aircrew reporting neck pain at the moment of performing the tests. The analyses did not reveal any differences between these groups, either.

To the best of our knowledge, no CROM data for helicopter rear aircrew have been published before. We hypothesized that, especially in this group, CROM would be lower in the neck pain subjects compared to the subjects without neck pain. With the surveillance and clearance tasks of the rear aircrew, they have to adopt extreme postures, with their head out of the window and rotated. We suggested that rear aircrew with a smaller cervical range of motion have to stress their cervical spine more to adopt these extreme postures, which could result in pain. The results, however, did not support our hypothesis.

Pilots and rear aircrew with neck pain did not differ in neck muscle strength, neck position sense or active cervical range of motion, compared to their colleagues without pain. These results suggest that these physical abilities, as assessed in this study, are not associated with neck pain in this population.

It has been suggested that, since the pilots and aircrew are a pre-selected population
with excellent physical capacities, the solution to flight-related neck pain may not be found in improving their physical abilities but, rather, in decreasing neck load. This might be accomplished by ergonomic improvements in the equipment used by pilots and rear aircrew.
References


Optimal helmet use and adjustments with respect to neck load: The experience of military helicopter aircrew

Chapter 7
Abstract

Introduction: One solution to prevent flight-related neck pain in military helicopter pilots is to initiate ergonomic improvements in the equipment used by the pilots and loadmasters. The aim of the present study was to identify factors that may be important for optimizing helmet use and adjustments with respect to neck load among the helicopter crew of the Royal Netherlands Air Force. A second aim was to identify the factors contributing to an ideal flight helmet.

Methods: We interviewed 12 pilots and 11 loadmasters using semi-structured interviews. The interviews were transcribed verbatim, and qualitative analyses were performed. Various factors as well as their interrelations and relation to experienced neck load emerged as the analysis progresses and were discussed by the research team.

Results: Factors that were directly related to the experienced neck load were type of flight operations and tasks as well as the weight and the weight distribution of the flight helmet. Factors that indirectly contributed to the experienced neck load were the stability of the helmet, the helmet fit and comfort. Factors that contributed to an ideal flight helmet were categorized into task- and user-related factors. The latter category included factors to increase comfort and usability as well as a considerable number of the above-mentioned factors to optimize helmet use and adjustments with respect to neck load.

Conclusion: Several factors related to helmet use and adjustments were found to contribute to the experienced neck load and were either directly or indirectly related. The next step should be to improve the helmet fit and the helmet stability taking the comfort issues into account, and to evaluate the effect of optimizing these factors on the experienced neck load.

Relevance to industry: Neck pain in military helicopter aircrew is of growing concern to various militaries, especially because flight missions occur more frequently in the dark and the aircrew use night vision goggles. The results of this study provide useful information to the flight helmet industry because the neck load and factors such as weight, weight distribution, helmet stability, helmet fit and comfort issues are important considerations for helmet designs and requirements.
Introduction

Background
Neck pain is a prevalent occupational health problem in military helicopter pilots [1;3;13;18] and loadmasters [17]. Military helicopter pilots fly helicopters that, depending on the type of helicopter, are used to transport troops and cargo, perform search and rescue missions, and provide close combat support for ground troops. The main tasks of the loadmasters, the aircrew working at the back of a transport helicopter, are troop management, material handling and surveillance and clearance tasks. Recently, we found that military helicopter pilots and rear aircrew from the Dutch Defense Helicopter Command (DHC), despite neck pain, have overall a good physical capacity of the neck [19]. Thus, it has been suggested that the solution to flight-related neck pain may not be in improving their physical capacity but, rather, in decreasing neck load. One solution is to make ergonomic improvements in the equipment used by the pilots and loadmasters.

The ergonomic situation when flying a helicopter, particularly the use of heavy head-worn equipment such as helmets, head up displays (HUD), night vision goggles (NVG) and counterweights (CW), has been suggested as an important contributing factor to flight-related neck pain [6;9;14]. In a recent survey, the majority of the Dutch military helicopter aircrew with neck pain reported NVG-use as a perceived cause of their neck pain [17;18]. The weight and position of the NVG to the front of the helmet causes changes in the center of gravity to move up and forward, which causes a higher load to the neck extensors [15]. The Royal Netherlands Air Force (RNLAF), like most other international militaries, has CW equipment that is optionally available to their aircrew to provide a balance to counter the weight of the NVG. Although some beneficial metabolic effects of CW use have been reported by helicopter pilots [9], there is little evidence of the relieving effect of CW equipment on neck load. Knight and Baber [11] even found higher muscle activity when a frontal load on a helmet was counterbalanced. Studies that recently investigated the effects of head and neck postures and head-worn equipment on the muscular responses of the neck provide us with a better understanding of the impact of these factors, but they were not performed in-flight and/or mainly concerned the working postures of the pilots and not of the rear aircrew [8;9;14]. The mission demands however, determine the postures adopted, the helmet configurations used, the flight duration, and their interactions and consequences on neck load. Therefore, as a first step, it is important to know what the in-flight experiences of pilots and rear aircrew are concerning their helmet configurations in relation to their experienced neck load.

Almost all helicopter pilots and rear aircrew from the RNLAF use CW equipment when flying with NVG, although there are no official guidelines or directions given to the aircrew for how to use them. Because guidelines do not exist, we were interested to know whether pilots and rear aircrew knew what the best helmet configuration was with
respect to neck load. The experience of the pilots and rear aircrew is of considerable value and reviewing their experience is a first step in trying to improve the ergonomic situation with respect to helmet use and adjustments made by the helicopter pilot and rear aircrew.

**Aims**
To prevent flight-related neck pain in the Dutch military helicopter aircrew, there is a need for ergonomic improvements in the equipment used by the pilots and loadmasters. The aim of the present study was to identify the factors based on the experience of the aircrew to be important in optimizing helmet use and adjustments with respect to neck load. A second aim was to elucidate the factors contributing to an ideal flight helmet according to the aircrew.

**Methods**

**Subjects**
Participants were helicopter pilots and loadmasters from two squadrons from the RNLAF flying the Chinook and Cougar helicopters, respectively. We started to interview 10 pilots and 10 loadmasters, but the exact number of participants was determined by the reach of data-saturation [16], as explained in the procedures and analyses section. The sample strategy was aimed at achieving a sample with a relevant diversity [5;12]. Based on earlier studies [10;18] and a discussion by the research team, we identified four factors that were important for diversity: gender, military flying experience, type of helicopter and the presence of flight-related neck pain.

We started with a convenience sampling strategy and contacted pilots and loadmasters who reported their willingness to participate in an interview first. At some point during the sampling we had to consider the four factors described above to achieve a relevant sample. The chief operating officer was asked to initiate contact between us and the pilots and loadmasters to help us assemble a sample with the greatest diversity (purposive sampling).

Participation was voluntary. Ethical approval for the study was waived because the interviews contained no topics that were subject to privacy constraints, and the data were stored anonymously.

**Procedures**
All interviews were conducted by the first author (woman, 36 years old, human movement scientist and human factor specialist in military aviation and with some experience in usability research) between November 2009 and January 2010. The face-to-face interviews were conducted in a private room in one of the squadrons. Participants received written information about the objectives, design and data confidentiality of the study one week prior to the interview. The interviewer asked the pilots and loadmasters
Interviews
We used semi-structured interviews. Basically this means that a list of key questions is prepared, but these can be asked in a flexible order and wording that is contextually appropriate [5]. Additional questions can be asked during the interviews for more information on particular points and to further explore some topics. Based on the aim of the study we prepared a number of questions. Then two pilot interviews were held with a helicopter pilot and loadmaster to practice the interview, and get familiarized with their professional language. The interview included topics such as the aspects of helmet adjustment that were important for optimizing neck load, counterweight use and the ideal flight helmet according to the interviewee. The questions are presented in Box 1.

Box 1. Questions in the semi-structured interview

- Is the neck load a concern when you use and adjust your helmet?
- What makes your helmet minimize neck load?
- Do you use counterweights? How do you determine the weight of your counterweights?
- Can you describe your ideal helmet?

Analyses
All interviews were audio taped and transcribed verbatim. We used the MAXqda software 2007 (Udo Kuckartz, Berlin, Germany) for coding the transcripts. Based on the interview questions and the aims of this study, we selected two topics to use as a framework for coding the transcripts: 1) factors for optimizing helmet use and adjustments with respect to neck load; and 2) factors contributing to the ideal flight helmet. The first author carefully read and open-coded all transcripts: the transcripts were divided in text fragments and relevant fragments were given a code representing this specific fragment and were assigned to one of the two topics. The aim of open-coding is to explore the field of research, covering the field by concepts and making the data workable [2;5]. The last author read and open-coded the first four transcripts independently of the first author to ensure reliability. The two researchers then
compared and discussed their selected text fragments and reached a consensus about the open-coding system. The first author subsequently open-coded the remaining transcripts. Next, the open-codes were organized into categories and subcategories that emerged as the analysis progressed and were discussed by the research team. For the first topic of factors contributing to helmet adjustment and configuration to optimize neck load, the interrelations of the main factors and the relations to experienced neck load were determined. The interviews were read again in chronologic order to verify the categories and relations and to verify data saturation [2;16;16].

Results

Subjects’ characteristics
A diverse group of helicopter aircrew was interviewed: 12 pilots (p) and 11 loadmasters (lm), four women and 19 men, nine flying the AS-532 U2 Cougar helicopter and 14 flying the ICH-47D Chinook helicopter. The mean total flying hours was 1824 (range 350-3700), the mean NVG hours was 258 (range 45-900) and the mean years in the air force was 15 (range 3-29). Two pilots and four loadmasters experienced flight-related neck pain, six pilots and four loadmasters experienced flight-related neck pain only after flying with NVG, and four pilots and three loadmasters never experienced flight-related neck pain. The duration of the interviews varied from 9 to 29 minutes.

Important factors to optimize helmet use and adjustment with respect to neck load.
The first aim of this study was to identify important factors to optimize helmet use and adjustments with respect to neck load according to the aircrew. The analyses of the interviews revealed six factors: 1) the flight operations with flight helmet; 2) the weight of the helmet and mounted equipment; 3) the weight distribution of the helmet and mounted equipment; 4) the stability of a helmet in all its configurations; 5) the helmet fitting; and 6) the comfort of the helmet. The interrelations of these factors and the relations with neck load experienced by the aircrew are illustrated in Figure 1. The first three factors were directly related to the experienced neck load. The factors “weight” and “weight distribution” were also related to each other as the weight and the center of gravity of the helmet, NVG and CW determined the weight distribution, and the use of counterweights to optimize the weight distribution determines the total weight. The factor “stability” was indirectly related to experienced neck load because of its influence on the “weight” and because it was influenced by the “weight distribution”. “Helmet fitting” was indirectly related to experienced neck load through its influence on “stability” and “comfort”; “comfort” had a two-way relationship with “stability” and was thus indirectly related to experienced neck load. How the six factors were related to the experienced neck load is explained below.
Figure 1. Factors contributing directly and indirectly to experienced neck load.

NVG=Night Vision Goggles, HUD=Head Up Display, CW=Counterweights
Flight operations wearing flight helmet

Wearing a flight helmet during flight was a factor contributing to the experienced neck load. The type of work of the aircrew in the cockpit and in the back of the helicopter, the duration of the flight, the movements they made and the postures they adopted in combination with wearing the helmet contributed to the experienced neck load (see quote participant lm06).

“I experience neck load because of flying while wearing a helmet. The helicopter vibrates and so does the helmet (…) and to keep a good view you have to move a lot with your head (…) with slings you hang upside down and you feel the weight of the helmet, you have to work with your neck muscles to keep your head up…” (lm06)

Within the context of the tasks that pilots and loadmasters performed, the preferences of helmet adjustments differed between individuals, which were illustrated by the quotes of participants lm07 and lm10. While the first preferred to fly with a counterweight during a navigation flight at night, the latter preferred to remove the counterweight in this scenario.

“When we are going to do a navigation flight at night, meaning 2 hours flying above land, I use a counterweight. However, when we are going to do slopes or slings, I remove the CW because you hang outside and/or upside down, and then I prefer as little weight as possible”. (lm07)

“When we are doing just a navigation flight during the night, sometimes I take off the CW because you do not move that much. However, when you really have to do intensive physical work, I prefer the CW”. (lm10)

Weight

The total weight of the helmet in combination with the HUD or NVG and CW equipment were thought to directly determine the experienced neck load. Although the weight of the helmet, HUD and NVG could not be changed by the aircrew, they took the total weight into account when choosing the weight of their counterweights. The reasons for using a CW could be weight distribution or to prevent the helmet from sliding (explained below). However, the aircrew did not always completely compensate for the weight of the goggles with the CW because they preferred to minimize the total weight as much as possible (see quotes participants lm11 and p04).

“It has been explained to me that using a CW will reduce the feeling of my head falling forward when flying with NVG, but it is extra weight loading on your cervical spine… when the weight of the CW is too heavy, it becomes uncomfortable (…) well, you can put a kilo at the back of the helmet, which will definitely prevent your helmet from falling forward, but that is not very pleasant because you feel the total weight, and it is better to have as little weight as possible on your head”. (lm11)
“The counterweight I use is 350 gram (…) during flights in the dark; I am still busy with my helmet to keep it straight up. So you would think that the weight of my counterweight is not enough, but I think enough is enough (…) It becomes heavier and heavier. After some hours of flying with NVG, my neck becomes stiff. This is a clear sign of my body telling me that there was a lot of weight on my head”. (p04)

**Weight distribution**

Pilots and loadmasters mentioned the weight distribution as directly impacting the experienced neck load. They tried to create the most optimal weight distribution when flying with a HUD or NVG by using a CW. The placement and the weight of the CW were important factors in creating the optimal distribution. The optimal weight of the CW was determined by the aircrew intuitively and by trial and error. The aircrew mentioned that they did not know whether they could trust their intuition by searching for the right CW for the most optimal weight distribution with respect to the neck load (see quote participant p11).

“The weight of the goggles is so heavy, it has to be compensated you see (…) so you do not continuously have to strain your neck muscles to keep your head straight up, you will anyway, but just the weight of your head is what you are used to and then with the NVG (…) if you can balance the weight by using a CW, then there is more weight on your head, but it feels like you have to work less with your muscles(…) but maybe my feeling is not telling me what is the best for my neck and maybe I could do with less CW…” . (p11)

When flying with NVGs, there were situations when the NVG had to be folded, which changed the weight distribution. In that situation, the originally determined CW no longer provided the optimal distribution (see quote participant p12).

“To minimize neck load, I think balance of the helmet is really important, and the total weight of course should not be too heavy (…) but when everything is in balance, and I fold up the NVG, the balance is gone, and it feels awkward (…) you feel the helmet and everything leaning forward again…”(p12)

**Stability**

The sliding of the helmet had an indirect negative influence on the experienced neck load through weight distribution because it caused changes in the weight distribution. The aircrew mentioned that a CW in this case was not initially used to create the optimal weight distribution but was used for preventing the helmet from sliding during flight (see quote participant lm03).

“I started with a helmet one size larger and after 1.5 year, I got one size smaller. When I was flying with the larger helmet, I needed much more counterweights just to keep the helmet in place, now I could do without a CW (…) although it is still more comfortable to use a CW
because of the better weight distribution, but I do not need it anymore to keep my helmet in place”. (lm03)

Other measures of adjustment to prevent the helmet from sliding were the use of a different type of innerliner, tightening the nape and chin strap, fixing the helmet firmly on the ears and the use of a smaller helmet size when flying with HUD or NVG (see quote participant p04). A consequence of a sliding helmet when flying with HUD or NVG was that this visual equipment was no longer aligned with the eyes. To maintain a good view, the aircrew corrected this alignment by changing the position of their neck/head, which led to an unfavorable posture and to neck load. Stability was related to all other factors by 1) the use of CW increasing stability (weight and weight distribution), 2) a good fit increasing stability and 3) measures to tighten the helmet to increase stability ended up decreasing comfort, and the aircrew tried to find a balance in comfort and stability (see quote participant p04)

“During my deployments in Afghanistan, I flew with a smaller size helmet than I usually do because that smaller size is tighter on my head (…) I need to use the HUD, and when I fly with my large helmet, I really have to use a lot of CWs, but I do not want that because of the neck load, and the HUD is not aligned with my eye because of helmet sliding. Thus, I prefer the smaller helmet size fixed to my head in that situation, so I need less or no counterweight… back home, I use the large helmet because I do not like the pressure on my forehead… I think back home, when the flight duration usually does not extend 2 hours I do not mind correcting the helmet (pushing it up) continuously, and I fly with a heavier CW then (…) without an NVG, a large helmet is much more comfortable because of more ventilation”. (p04)

Helmet fit(ting)
A good fit of the helmet was thought to contribute to the experienced neck load by means of its influence on stability and comfort (see quote participant p02).

“The better the fit of the helmet, the less you will suffer from the weight. When the helmet is fixed on your head, it feels better; you still have to deal with the neck load, but it is more positive, the experience of the weight is more positive” (p02)

Factors that contributed to a lack of fit were 1) limited available helmet sizes; 2) type of innerliner 3) the initial helmet fitting being done without NVG even though one flies with NVG (the fit should have considered all configurations of use); 4) lack of or a variety in the skills of the personnel that perform the initial fitting; 5) the initial fitting being done in a static setting, whereas a good fit during flying needed to be determined; and 6) the fit could change with time with use of the helmet, emphasizing the need for regular fitting checks. Helmet fit(ting) was related to stability and comfort because a good fit would increase comfort and decrease the sliding of the helmet.
Comfort
Comfort partly and indirectly influenced the experienced neck load. The aircrew made adjustments to their helmet to decrease discomfort. The napestrap should not be tightened too much because it would give an awkward feeling to the neck muscles. The helmet should not be fixed too tightly because it would cause discomfort. Comfort was related to stability because when the helmet was loosely fixed, this likely decreased the stability (see quote participant lm10).

“The helmet wants to turn over no matter how much you tighten the napestrap. OK, it helps a little to tighten the napestrap, but if you really tighten it, it feels awkward in your neck, so that is really no option”. (lm10)

The type of innerliner was also mentioned to decrease the feeling of pressure points, the so-called “hotspots”, and to increase the overall comfort. However, the type of innerliner providing the most comfort was not necessarily the innerliner for the best stability. Also, the same type of innerliner could cause different effects on the helmet stability for different aircrew personnel (see quote participant p08 vs. quote participant lm10).

“I fly with a different type of innerliner (type B) now, which gives me much more comfort. A disadvantage, however, is that with this innerliner, there is more movement in the helmet”. (p08)

“The type of innerliner is a factor contributing to less neck load. Since I have been using this innerliner (type B), it is much better because with the other innerliner (type A), my helmet was sliding over my head continuously, and with innerliner type B, the sliding has reduced a lot”. (lm10)

Factors contributing to an ideal flight helmet
The second aim of this study was to determine which factors were important to the aircrew to make them satisfied with their helmet. The open-codes were ordered and categorized in 12 factor groups. These factors could be divided into factors needed to be able to perform their tasks (task-related factors) and factors related to optimize helmet use, to “make things easier” (user-related factors). The two categories with the factors are shown in Table I.

Task-related factors
The task-related factors that the ideal helmet should meet were as follows: no obstruction of sight; protection of face, eyes, head and hearing (see quote lm03); allowing for good communication; and not causing any head movement constraints.
“The ideal flight helmet should protect my hearing. For me that’s the most important. Of course the helmet should also give protection for a punch in the cabin...and protection to dust. We fly in dust for years now, but with the current helmet we are not protected. So there’s room for improvements...also at night I would like something as a visor for protection of face and eyes. Because of the goggles you can not lower the visor and with cold weather your eyes water and this will freeze.” (lm03)

**Table I.** Factors contributing to an ideal flight helmet.

<table>
<thead>
<tr>
<th>Factors contributing to the ideal flight helmet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task-related factors</strong></td>
</tr>
<tr>
<td>No obstruction of the visual field</td>
</tr>
<tr>
<td>Protection of face, eyes, head and hearing</td>
</tr>
<tr>
<td>Allows for good communication</td>
</tr>
<tr>
<td>Will not cause any head movement constraints</td>
</tr>
<tr>
<td><strong>User-related factors</strong></td>
</tr>
<tr>
<td>Good thermoregulation properties</td>
</tr>
<tr>
<td>Good fit and size options</td>
</tr>
<tr>
<td>Stability and no sliding of the helmet</td>
</tr>
<tr>
<td>Weigh as little as possible</td>
</tr>
<tr>
<td>One unit in all configurations / compatibility</td>
</tr>
<tr>
<td>Not causing any discomfort</td>
</tr>
<tr>
<td>Not being aware of wearing a helmet</td>
</tr>
<tr>
<td>User-friendly</td>
</tr>
</tbody>
</table>

**User-related factors**
The user-related factors mentioned were: good thermoregulation properties; good fit and size options; the helmet should be stable and not able to slide; light in weight; the helmet should be one unit in all its configurations and/or compatible to all needed mounted equipment (see quote participant p08); user friendly; and should not cause any discomfort (see quote participant lm01). In the most ideal situation, one should not be aware of wearing a helmet (see quote participant p09).

“...now it is the battery pack fixed at the back of the helmet that is plugged in the NVG on the front, so there is a cord (…) there are a lot of pieces and cords, it is not very modern. The ideal helmet should be light with everything in it without bulges and cords”. (p08)

“The ideal helmet should be comfortable (…) The lighter the better; however, a light helmet with less comfort or a somewhat heavier helmet that offers more comfort, I will chose more
comfort because when I have to wear that helmet for nine hours, it is nice when it is 100 gram lighter, but when I feel 16 pressure points, then I do not want the lighter helmet” (lm01)

“The ideal helmet (…) is one that you are not aware of when wearing it. It should not restrict you in your movements (…) it should be very light such that you are really not aware of wearing it; that is the ideal helmet” (p09)

Discussion

In this study, we explored factors that were important to optimize helmet use and adjustments with respect to neck load as identified by the helicopter aircrew from the RNLAF. We did this as a first step in trying to improve the ergonomic situation of the helicopter pilot and loadmaster when flying. Three main factors were found directly related to the experienced neck load: performing tasks in-flight, weight of the helmet and mounted equipment and the weight distribution of the helmet and the mounted equipment. Furthermore, three factors were identified as indirectly contributing to experienced neck load: the stability of the helmet, the helmet fit and adjustments to the helmet to decrease discomfort. A second aim of this study was to identify what factors contributed to the ideal flight helmet according to the aircrew. The helicopter crew reported that, besides task-related factors, a variety of user-related factors, which included factors to increase comfort and usability as well as factors mentioned to optimize helmet adjustments with respect to the experienced neck load, were features of an ideal flight helmet.

The three factors identified in this study that were directly related to the experienced neck load (see Figure 1) are in line with what would have been expected from a biomechanical point of view. NVGs alter the helmet gravity forward, and CW alters it backwards [7]. Thuresson et al. [15] showed with a simplified biomechanical model, using static biomechanical analysis, that the induced flexing load moment from the head and the helmet increased in the neutral position when NVG were added to the helmet and decreased from that level when CW was also added. In a flexed position, however, the ameliorating effect of the CW was not as prominent as in the neutral position. This finding confirms the results of another study that showed that the more the neck is flexed, the less the CW reduces the momentum force and eventually turning it into a loading movement for the neck [7]. Recently, Forde et al. [4] found that helicopter pilots significantly spent more time in a flexed neck posture during night flights compared to day flights. They investigated the neck postures and neck loads during simulated day and night flights. Their results suggest that the additional mass added by the NVG requires the pilots to assume awkward postures during flight and results in an increase in the cumulative load placed on the pilot’s necks. Thus, it might be of no surprise that the factors of weight and weight distribution were brought up by the aircrew in the
present study and that they mentioned that wearing the flight helmet and the mounted equipment in combination with performing their tasks in-flight influenced their experienced neck load. When performing their tasks, the aircrew had to adopt different postures, and as revealed by Thuresson et al. [15], the increased load caused by different postures seems to have a greater influence on muscle activity than the increased load of the head-worn equipment. In particular, the loadmasters mentioned that the use of CW equipment depends on the flight mission and the tasks they have to perform. This sounds logical because CW equipment can increase the loading moment as described above, depending on the head and trunk position. However, the results of this study revealed that preferences of CW use differ between aircrew performing specific tasks with presumably similar adopted postures. It would be interesting to further investigate this phenomenon. Do loadmasters indeed use the same postures performing the same tasks? Another explanation for using different amounts of counterweights might be the fact that aircrew use counterweights for different reasons as explored in the current study. It was mentioned that loadmasters use counterweights to create balance in the weight distribution, but also to prevent the helmet from gliding.

In addition to factors directly related to the experienced neck load, some other factors were mentioned by the aircrew that were indirectly related to the experienced neck load: helmet stability, helmet fit(ting) and comfort. As shown in figure 1, some specific adjustments were mentioned for all three factors. For example, to increase the stability of the helmet and to prevent it from sliding, pilots and loadmasters tighten the napestrap. However, when they tightened the napestrap too much, it gave them an uncomfortable feeling, and this led them to loosen the strap. This loosening will decrease stability and eventually affect the weight distribution when the helmet is sliding during flight. Moreover, the better the fit of the helmet, the less the need for adjustments to increase stability (such as tightening the napestrap) and the more comfortable it will be for the aircrew. Another example of adjustments that affect stability, helmet fit and comfort was the type of innerliner used. The aircrew mentioned choosing specific types of innerliners to decrease discomfort. However, the type of innerliner could also increase or decrease the stability of the helmet, and a better or worse fit can be brought about by the type of innerliner. Therefore, given that the same adjustment can be made for different reasons, when the adjustment was made for one reason, the effect of the adjustment on the other factors should be considered.

It became very clear from the interviews that the fit of the helmet was very important to the aircrew but that the optimal fit was not easily achieved. Several aspects of the fitting procedures were criticized by the aircrew. They emphasized the need for highly-skilled personnel to do the fitting and the need for fit checks at different times because the experience of flying with the helmet and NVG changed the conditions for achieving a good fit. The results suggest that a critical evaluation of the fitting procedures could result in improvements and better helmet fits for the aircrew.

To the best of our knowledge, the factors of stability, helmet fit and comfort were never taken into account in studies investigating neck load in the military aircrew. These
factors that indirectly impacted the experienced neck load were important and should be considered in further research. Improvements in helmet fit and stability as well as comfort should be made, and their impact on the experienced neck load should be evaluated. This information is necessary not only for the users of the helmets and the mounted equipment to optimize neck load, but also for the helmet industry that consider neck load and factors such as weight, weight distribution, helmet stability, helmet fit and comfort issues in their designs and requirements.

The task-related factors mentioned by the aircrew when describing their ideal flight helmet are clear and cover the role of the flight helmet which is initially providing impact protection and hearing and eye protection. Furthermore the helmet can facilitate communication which is necessary for pilots and loadmasters to perform their tasks. Aircrew mentioned that within the ideal flight helmet communication should be optimized. Within the user related factors, a considerable number of the factors mentioned by the aircrew contributing to their experienced neck load, such as weight, stability, fit and comfort, were mentioned. The results of this inquiry, however, might not come as a surprise because the question about describing the ideal flight helmet was always the last question after the interviewees talked extensively about factors contributing to neck load. However, these results confirm that besides factors necessary to perform their tasks, aircrew mention the importance of the absence of feelings of discomfort caused by the use of the flight helmet and they also mentioned their health concerns. These results should be taken into consideration by the employer when a new flight helmet has to be purchased.

Conclusions and further research
According to the aircrew, the factors of weight and weight distribution of the helmet and mounted devices determined the experienced neck load. However, the results of this study suggest that some additional factors should be taken into account when trying to reduce the experienced neck load caused by wearing a flight helmet and mounted equipment, such as the performance of certain tasks in-flight by the helicopter aircrew. In particular, certain tasks of the loadmasters, who spend a great deal of time performing dynamic body movements, play a part in helmet adjustments that have consequences for the experienced neck load. To obtain additional insight into the biomechanical consequences of wearing a helmet with mounted equipment, future fundamental research should not only take the adopted postures of pilots but also the adopted postures and movements of loadmasters into account.

Besides directly related factors, several indirectly related factors that influence the experienced neck load were explored in this study. The factors of helmet stability, helmet fit(ting) and adjustments to reduce discomfort were interrelated and might indirectly influence the aircrew’s experienced neck load. Improvements in helmet fit(ting) and stability that take comfort issues into account should be suggested, and their impact on the experienced neck load should be evaluated.
Prevention of flight-related neck pain in military aircrew

References

The effect of an optimised helmet fit on neck load and neck pain during military helicopter flights

Chapter 8
Abstract

The main purpose of this study was to improve the helmet fit of military helicopter aircrew members and evaluate its effect on the experienced helmet stability (helmet gliding), neck load, neck pain, hot spots (pressure points), irritation/distraction, and overall helmet comfort during night flights.

A within-subject design was used over a three-month period that consisted of two consecutive interventions of optimising the fit of the aircrew’s helmets: 1) a new helmet fit using a renewed protocol and 2) replacement of a thermoplastic inner liner with a viscoelastic foam inner liner. A total of 18 pilots and loadmasters rated the outcome measures using the Visual Analogue Scales immediately after their night flights, for three night flights in total per measurement period.

The optimised helmet fit resulted in a significant decrease in the experienced helmet gliding, neck load and pressure points, a decrease trend in the experienced neck pain and irritation/distraction, and a significant increase in the experienced overall helmet comfort during flight.

These results demonstrate the importance of achieving an optimised helmet fit for military helicopter aircrew and that an optimised helmet fit might have implications for both health and safety concerns.
Introduction

Neck pain in military helicopter aircrews is a recognised aeromedical problem [2;19]. It has been suggested that neck pain may interfere with flying performance [16], and therefore, neck pain should be prevented not only for health but also safety reasons. Several factors have been associated with the prevalence of flight-related neck pain including awkward flight postures and wearing heavy head equipment [1;8;18]. Helicopter pilots are forced to sit in a slouched posture with a slight twist of the body to the left to control the helicopter because the cockpit is designed with the collective pitch lever on the left side of the pilot’s seat and the cyclic stick between the pilot’s legs [15]. The main tasks of the loadmasters, the aircrew working at the back of the helicopter, are troop management, material handling, surveillance, and clearance tasks, which often require extreme body and head postures [13]. Military helicopter pilots and loadmasters wear helmets and Head Up Displays (HUD) and use Night Vision Goggles (NVG) during night operations. The design requirements of the flight helmet maintain that the centre of gravity of the helmet should be close to the head’s centre of gravity to increase stability and minimise the load moments that impact the cervical spine. However, NVGs and HUDs not only increase the weight the head must bear but also alter the centre of mass forward and upward in relation to the motion axis of the cervical spine [10]. Most pilots and loadmasters counteract this misbalance by using a counterweight situated posteriorly at the base of their helmets (photo 1). It is the aircrew’s choice to use counterweights, and the weight used varies individually from 50 to 400 grams.

These reported risk factors suggest a biomechanical basis to flight-related neck pain in helicopter aircrews with a positive relationship between neck load and neck pain. The reported effects of counterweights when flying with NVGs, however, have been equivocal. Harrison et al. [11] reported beneficial metabolic effects of counterweight use, whereas Knight and Barber [14] reported increased muscle activity when a frontal load on a helmet was counterbalanced.
Helicopter aircrews have a dynamic job, and the demands of the mission determine the postures adopted, the helmet configurations used, the flight duration, and their interactions and consequences on neck load. The experience of the helicopter aircrew is therefore of considerable value in identifying the important factors related to optimising helmet use and adjustments with respect to neck load. Therefore, we recently interviewed our helicopter aircrew and performed a qualitative study[20]. The flight demands, the weight of the head equipment worn and the weight distribution were identified as factors directly related to the neck load experienced by the helicopter aircrew. However, three other factors were mentioned by the aircrew that might impact their experienced neck load: helmet stability, helmet fit and comfort (Figure 1). Helmet stability was identified as a factor that impacts weight distribution and thus as a factor indirectly related to the neck load experienced. If the helmet is not stable, it might glide over the head and consequently change the weight distribution compared to the centre of gravity of the head during flight. Helmet fit was related to stability and comfort because a good fit increased comfort and decreased gliding of the helmet (increase stability). It became clear from the interviews that while the fit of the helmet was important to the aircrew, an optimal fit was not easily achieved. One of the reasons was that some specific helmet adjustments, such as the type of inner liner used, the size of the helmet and the tightness of the straps, were mentioned by the aircrew to impact more than just one factor. For example, a smaller helmet with a specific inner liner and extremely tightened straps could increase the stability of the helmet but would lead to feelings of discomfort such as hot spots (pressure points). Our aircrew mentioned that discomfort during flying might cause them to be irritated and distracted, indicating the importance of not only a stable helmet but also a comfortable helmet fit. Although
comfort is not synonymous with the absence of discomfort [5], we believe that the absence of hot spots will increase overall helmet comfort. The results of our qualitative study suggest the need for a critical evaluation of the fitting procedures currently used by the Royal Netherlands Air Force (RNLAF) and a renewed helmet-fitting protocol. This renewed protocol should result in better helmet fits for the aircrew and greater helmet stability, taking issues of comfort into account.

Figure 1. Factors contributing to the neck load experienced during flights.

The purposes of this study were twofold: the first aim was to improve the helmet fit and evaluate its effect on the experienced helmet stability, neck load, neck pain, hot spots, irritation/distraction, and overall helmet comfort during flight; the second aim was to explore the assumed relations between helmet stability and neck load, between neck load and neck pain, between hot spots and comfort, and between hotspots, comfort, and irritation/distraction experienced during flight.

Methods

Design
A within-subjects design was used that consisted of two consecutive interventions of optimising the fit of the aircrew’s helmet and three measurements: before intervention, after the first intervention and after the second intervention.

Subjects
Participants were helicopter pilots and loadmasters from two squadrons from the Royal Netherlands Air Force who flew the Cougar or Chinook helicopter. All pilots and loadmasters of these squadrons who were on active flight status and were expected to fly at least nine night flights using NVGs within a period of 3 months during October 2010-March 2011 were eligible to participate. Participation was voluntary, and the participants gave their informed consent. Ethical approval was not requested, because the current study did not meet the criteria of the Medical Research with Human Subjects Act [22]. The study involved no medical research, the measures involved normal job
preliminary procedures and were executed in normal operating conditions of the RNLAF, and the evaluation of the measures involved a short questionnaire that contained no material subject to privacy constraints.

Interventions
The optimisation of helmet fit consisted of two parts. The first intervention involved a new helmet fit using a renewed protocol. This renewed protocol was the result of reorganizing the relevant chapters of the helmet’s operating instructions, results of our qualitative study [20] and the knowledge and experience of the helmet technicians of the flight equipment department. This resulted in a stepwise checklist divided in 4 main topics and illustrated with clear drawings. The first topic involved the determination of the helmet size, including several steps of measuring the head and selecting the correct size. The second topic involved the helmet preparation, including all steps from unpacking the new helmet from the box till inspecting all parts of the helmet and their correct positions. The third topic involved the instructions to correctly put on the helmet, an activity that has to be carried out several times during the fitting procedure. The fourth topic involved all steps needed to actually fit the helmet and was subdivided in the following items: fitting the inner liner and relieving hot spots, positioning of the ear cups and adjustment of the ear cushion pressure, adjustment of the chinstrap and the neck strap, adjustment of the visors, mounting the NVG, and checking the stability and fit of the helmet with NVG. The main changes compared to the previous fit were that in the renewed protocol all steps necessary to fit a helmet were pooled, instead of spread throughout the helmet’s operating instructions; additional warnings were inserted at crucial steps within the protocol where mistakes could easily and unnoticeably be made; and skilful tricks and tools were provided to aid the technicians during certain steps. To fit the helmet according to this protocol, all aircrew received a new thermoplastic inner liner fitted in their helmet and adapted according to the protocol to achieve the best fit. The thermoplastic inner liner is the standard inner liner provided with the flight helmet by the helmet manufacturer. It is comprised of four layers of thermoplastic sheets covered with a washable cloth cover. Individual fitting is accomplished by removing layers or parts of layers of the thermoplastic sheets. If further individual fitting is needed, the liner can be heated, the thermoplastic layers become pliable and the individual puts on the helmet with the heated liner until the sheets have cooled. At least one familiarisation flight was included to acclimate the aircrew to the new fit, and further adaptations to the fit were made after this familiarisation flight, if necessary. This procedure was described in and part of the renewed fitting protocol.

The second intervention involved a new type of inner liner. The thermoplastic inner liner was replaced with an inner liner made of viscoelastic foam. This liner is a commercially released liner and is comprised of sections of viscoelastic foam sewn into a washable cloth outer covering. The viscoelastic foam compresses under the weight
of the helmet and conforms to the contours of wearer’s head, providing a custom fit. Impact protection tests performed by the U.S. Army Aeromedical Research Laboratory have shown that the use of this new type of liner in the helmet does not affect the impact protection of the helmet [4]. The helmet fit was rechecked with this new inner liner and adapted if necessary.

Both interventions took place at the building of the flight equipment department located on the same base as the two participating squadrons. Before the start of the study, both interventions were practiced with two fitting experts of the flight equipment department by two ergonomists (YS and MO).

**Procedures**

The chief operating officers of both squadrons selected all eligible aircrew. The study was explained to the selected aircrew in an oral briefing, and written information was also provided. Immediately after every night flight, aircrew filled in a form that contained several questions about the past flight and rated their perceived helmet stability, neck load and neck pain, hot spots, distraction/irritation, and comfort during the past flight for this fit. It took less than five minutes to complete the form. The aircrew placed the completed form in an envelope and dropped it in a box. To ensure the forms were filled in immediately after the flight, the researcher (MO) sent reminder e-mails on the day of the flight and the envelopes were counted the next day before the aircrew arrived at the squadron.

The time line of this study is illustrated in **Figure 2**. During the baseline, participants flew their night flights with their current helmet fit, including their current inner liner, NVG and optional counter weights. After an individual aircrew member had flown and evaluated three night flights, an appointment was made to fit their helmet according to the renewed protocol (intervention 1). After three further night flights were flown and evaluated following intervention 1 (excluding the familiarisation flight), the

![Figure 2. Time line of the study. NF = night flight](image-url)
thermoplastic inner liner of the helmet was replaced with the viscoelastic foam inner liner, and the helmet fit was rechecked (intervention 2). After flying and evaluating another three night flights, the individual aircrew member had completed the study. All interventions in this study were performed by two trained fitting experts of the flight equipment department and one ergonomist (YS). Another ergonomist (MO) was always present to supervise the proceedings.

**Outcome measures**

The dependent variables were the following: experienced helmet stability (helmet gliding), hot spots (pressure points), neck load, neck pain, irritation/distraction, and overall helmet comfort during flight. These were rated using separate Visual Analogue Scales (VASs). Each VAS consisted of 100 mm lines bounded by two short vertical lines and another short vertical line at 50 mm to indicate the middle of the line. The verbal anchors for experienced helmet gliding, pressure points and irritation/distraction during flight were “no suffering from helmet gliding/pressure points/irritation or distraction at all” on the left side of the scale and “extreme suffering from helmet gliding/pressure points/irritation or distraction at all” on the right side of the scale. For experienced neck load during flight, the verbal anchors were “hardly any neck load” on the left side of the scale and “extreme neck load” on the right. For experienced neck pain during flight, the verbal anchors were “no pain or aches at all” on the left side of the scale and “extreme pain or aches” on the right. For experienced overall helmet comfort, the extremes were “very little comfortable” on the left side of the scale and “very comfortable” on the right. In addition to the VASs, the aircrew answered several questions about the current flight, such as flight duration, tasks performed during flight (only the loadmasters), counterweight (CW) use and amount, and current inner liner type.

**Analyses**

Statistical analyses were performed using the SPSS 16.0 software package (SPSS Inc, Chicago, IL). Means for each dependent variable were obtained by calculating the mean VAS score of a minimum of two flights for base line (T1), T2 and T3. The means of each dependent variable and flight duration were compared within subjects using ANOVA-repeated measures. If there were significant differences, Bonferroni post hoc tests were performed. For the second aim, the relation between experienced helmet stability (helmet gliding) and neck load, between neck load and neck pain, between hot spots (pressure points) and comfort, and between hot spots (pressure points), comfort and irritation/distraction were measured at T3 using Pearson’s correlation coefficients. For all outcome measures, a statistical significance was defined as p<0.05.
Results

Participants and flight information
A total of 18 helicopter aircrew members, 9 pilots and 9 loadmasters, 10 flying the cougar helicopter and 8 flying the Chinook helicopter, completed the study in the study period. Their average age, height and weight (±SD) were 31 yr (± 10), 183 cm (± 8) and 80 kg (± 8). In terms of flying experience, their average total flying hours were 1192 hours (±1085), and average hours flown with NVG were 215 hours (± 259). All but two crewmembers evaluated three night flights after both interventions; two loadmasters completed two evaluations after the second intervention.

Mean flight duration was 2.4 hours (± 0.7) at T1, 2.1 hours (± 0.5) at T2 and 2.7 hours (±0.6) at T3. Post hoc analyses showed a significance difference in flight duration between T2 and T3. Counterweights varied from 150 grams to 400 grams between individuals; mean counterweights did not differ within subjects between T1, T2 and T3.

Effect of an optimised helmet fit (first aim)
The optimised helmet fit showed a significantly decrease in the experienced helmet gliding (p<0.000), neck load (p=0.02) and pressure points (p=0.001), a nearly significant decrease in the experienced neck pain (p=0.058) and irritation/distraction (p=0.057), and a significant increase in the experienced overall comfort (p<0.000) during flight (Figures 3 and 4).

The mean VAS scores for each outcome measure are shown in Table I.

Neck pain experienced during flight was reduced after the helmet was refitted and was further reduced with the viscoelastic foam inner liner. The aircrew reported no change in irritation/distraction after the new helmet fit, but they were less irritated or distracted after the viscoelastic foam inner liner was fitted in their helmets.

Table I. VAS scores for the different outcome measures at baseline (T1), after a refitted helmet (T2) and after the implementation of a viscoelastic foam liner (T3).

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
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<tbody>
<tr>
<td></td>
<td>Mean (± SD)</td>
<td>Mean (± SD)</td>
<td>Mean (± SD)</td>
</tr>
<tr>
<td>Helmet gliding</td>
<td>60 (16)</td>
<td>27 (21)*</td>
<td>25 (23)*</td>
</tr>
<tr>
<td>Neck load</td>
<td>42 (22)</td>
<td>32 (21)</td>
<td>30 (23)*</td>
</tr>
<tr>
<td>Neck pain</td>
<td>39 (24)</td>
<td>33 (23)</td>
<td>26 (21)</td>
</tr>
<tr>
<td>Pressure points</td>
<td>52 (22)</td>
<td>53 (27)</td>
<td>27 (21)* †</td>
</tr>
<tr>
<td>Distraction</td>
<td>46 (22)</td>
<td>46 (29)</td>
<td>30 (23)</td>
</tr>
<tr>
<td>Comfort</td>
<td>40 (15)</td>
<td>49 (24)</td>
<td>66 (20)* †</td>
</tr>
</tbody>
</table>

Post hoc analyses were performed for helmet gliding, neck load, pressure points and comfort.
* p < 0.05 compared to T1, † p < 0.05 compared to T2
Figure 3. Mean experienced helmet gliding, neck load and neck pain during night flights at baseline (T1), after a refitted helmet (T2) and after the implementation of a viscoelastic foam inner liner (T3).

Figure 4. Mean experienced hot spots, irritation/distraction, and overall helmet comfort during night flights at baseline (T1), after a refitted helmet (T2) and after the implementation of a viscoelastic foam inner liner (T3).
Post-hoc analyses were performed for the following outcome measures: helmet gliding, neck load, pressure points and comfort. These analyses revealed a significant decrease in helmet gliding during the night flights after the helmet was refitted followed by a small non-significant decrease after the implementation of the viscoelastic foam inner liner. The effect of the optimised helmet fit on the experienced neck load during night flights was achieved by a reduction in neck load after the aircrew’s helmets were refitted, followed by a further smaller reduction after the viscoelastic foam inner liner was fitted in the helmets of the aircrew members.

The occurrence of pressure points were slightly higher after the new helmet fit but decreased significantly after the viscoelastic foam inner liner was fitted.

A non-significant higher overall comfort in the fit of the helmet during the night flights was experienced by the aircrew after the first intervention followed by a further significant increase in overall comfort with the viscoelastic foam inner liner fitted in the helmet.

**Associations between variables (second aim)**

The results for the associations between the experienced helmet stability (helmet gliding) and neck load, between neck load and neck pain, between hot spots (pressure points) and overall comfort, and between both hot spots and comfort and irritation/distraction are shown in Figure 5. There was a significant positive correlation between

![Diagram](image.png)

**Figure 5.** Correlations between helmet gliding and neck load; between neck load and neck pain; between hot spots and comfort; between hot spots and distraction/irritation; and between comfort and distraction/irritation. **Correlation is significant at the 0.01 level.**
helmet stability (helmet gliding) and neck load, $r=0.70$ ($p<0.01$), with higher perceived neck load during flights associated with higher suffering from helmet gliding. Neck load was significantly positively correlated with neck pain, $r=0.80$ ($p<0.01$). There was a significant strong correlation between hot spots and overall comfort, $r=-0.79$ ($p<0.01$), with higher comfort levels associated with lower suffering from hot spots during the night flights. Both suffering from hotspots and overall comfort were significantly correlated with irritation/distraction, $r=0.78$ and $r=-0.82$, respectively, ($p<0.01$), with higher suffering from hot spots and lower overall comfort associated with higher irritation/distraction.

**Discussion**

**Main results**

With an optimised helmet fit, helicopter aircrew members experienced less neck load, greater helmet stability, fewer hot spots and more comfort. Furthermore, a decrease trend was observed in experienced neck pain and irritation/distraction during their night flights.

The second aim of the study was to explore assumed relations between specific variables. Significant positive associations were found between helmet gliding and neck load, between neck load and neck pain, and between hot spots and irritation/distraction experienced during flight. Significant negative associations were found between hot spots and overall helmet comfort and between comfort and irritation/distraction experienced during flight.

**Helmet stability, neck load and neck pain**

To prevent flight-related neck pain in military helicopter aircrews, ergonomic improvements must be made to the equipment used. As a first step, we previously explored the in-flight experiences of pilots and loadmasters concerning their helmet configuration in relation to their experienced neck load [20]. Factors identified in that study, such as helmet fit, helmet stability and helmet comfort, were the focus in the present study because they could be indirectly related to neck load during flight. Taking the learned discomfort issues into account, we hypothesised that optimising helmet fit would increase helmet stability and decrease neck load during flight. The results of the present study confirm our hypothesis: the experienced helmet gliding and neck load during flight decreased significantly after the helmet was refitted and were highly associated with each other. These results suggest that a significant improvement in helmet stability can be achieved by refitting the helmets of aircrew that are on active duty and results in less neck load during flight. It should be stressed that optimising an aircrew member’s helmet fit does not merely involve following the manual of the helmet provider but requires professional skill and should not be underestimated.
Because the effect of an optimised helmet fit on neck pain was nearly significant (p=0.058), we decided post hoc to perform Bonferroni post hoc tests for this outcome measure as well. These analyses revealed a significant difference in neck pain between T1 and T3 (p=0.04). Considering the relatively small number of participants and the post hoc analyses, we believe that an optimised helmet fit might result in a decrease in neck pain during flight.

When planning these kinds of interventions in practice, one would like to predict what proportion of workers would benefit from the intervention. Therefore, we calculated the individual differences for helmet stability, neck load and neck pain between the time measurement periods, which revealed significant differences in the post-hoc analyses. Based on the values reported by others, who consider a difference of 9 to 13 mm using VAS scales as relevant [6;12;21], we agreed on 11 mm as a relevant difference. After the new helmet fit (the first intervention), 16 out of 18 participants showed a decrease in helmet gliding of more than 11 mm on the VAS scale, and after the viscoelastic foam innerliner was fitted (the second intervention), 17 out of 18 pilots showed a difference of more than 11 mm compared to baseline measurements. For neck load and neck pain, 10 out of 18 pilots and loadmasters showed a decrease of 11 mm on the VAS scale when the helmet was refitted and the viscoelastic foam inner liner inserted (T3) compared to baseline (T1).

By taking measurements immediately after flights and within a period of three months, we measured the short-term effects of the interventions. Hamberg-van Reenen et al. [9] evaluated localised musculoskeletal discomfort in workers during the working day using a 10-point scale. They found a relative risk of 2.6 for future neck pain (regular or prolonged pain in the past 12 months after a pain-free episode of 12 months) when discomfort ratings of at least 2 in the neck area were reported during a workday. The results of that study suggest that the short-term effects found in the current study of an optimised helmet fit on neck load and neck pain might result in a decrease in regular and prolonged neck pain in helicopter aircrew members in the long term.

**Hot spots, comfort and distraction**

Increasing the helmet stability would not be that difficult if comfort issues did not play a part. Helmet stability could be maximised simply by fitting the helmet as fixed and tight as possible, allowing no movement of the helmet in any direction. However, this would cause enormous discomfort and is therefore not desirable because of feelings of discomfort and safety concerns. Indeed, our results showed a high association between perceived hot spots and lower ratings of comfort and higher ratings of irritation/distraction during flight. Whereas the refitting of the helmet was intended to take comfort issues into account and certainly not decrease comfort to an unbearable level, it was hypothesised that particularly the viscoelastic foam inner liner would contribute to the perception of less hot spots and higher comfort. Above expectations, the renewed helmet fit alone as a first intervention did not worsen the perception of hotspots, and
the comfort ratings even increased. However, after the viscoelastic foam inner liner was fitted into the helmet as a second intervention, feelings of hot spots decreased significantly, and comfort ratings increased significantly. Furthermore, the positive effect of the first intervention on helmet stability and neck load did not change or even increased slightly after the viscoelastic foam inner liner was fitted into the new fitted helmets of the aircrew members.

The results of the post hoc analyses suggest that a significant improvement in helmet stability and decrease in neck load can be achieved by refitting the helmets. Furthermore, the viscoelastic foam inner liners appear to decrease the perceived hot spots and increase the level of comfort.

The high association between comfort and irritation/distraction during flight further suggests the importance of a comfortable helmet fit for safety concerns. Because the main analyses showed a nearly significant (p=0.057) effect of an optimised helmet fit on irritation/distraction, we decided to perform Bonferroni post hoc analyses, which revealed a significant difference after the second intervention, between T2 and T3 (p=0.03).

As mentioned above, for practitioners who consider these kinds of interventions, it is interesting to evaluate the proportion of aircrew members who benefitted from the interventions. For hot spots, irritation/distraction and comfort, we therefore calculated individual differences between the measurement periods. Assuming a relevant difference to be at least 11 mm on the VAS scales, the difference in VAS score in irritation/distraction between T2 and T3 was at least 11 mm for 9 of the 18 aircrew members. For the perceived hot spots, there was a relevant difference in 12 out of the 18 aircrew members between T2 and T3 and in 13 out of the 18 aircrew members between T1 and T3. For comfort, 11 of the 18 aircrew members showed a relevant increase in comfort after the viscoelastic foam inner liner was fitted (T3) compared to only the new helmet fit (T2), and 13 out of 18 aircrew members showed a relevant increase in comfort compared to baseline (T1).

**Further implications**

Two risk factors often associated with neck pain in military helicopter pilots are awkward flight postures and heavy head equipment [17]. The optimised helmet fit in the current study resulted in a more stable helmet, and helmet stability might influence neck postures during flight. Forde et al. [7] investigated neck loads and neck postures in the Canadian Forces helicopter pilots during routine simulator day and night flights. They reported significantly greater percentages of time spent in mild and severe neck postures during night flights compared to day flights. They reasoned that the reduction in peripheral vision caused by NVGs required the pilot to flex and rotate his head more than during day flights. In addition to this explanation, our helicopter aircrew reported that an unstable helmet can also force them to modify their neck posture to keep the NVG aligned with their eyes[20]. Therefore, an optimised helmet fit that increases the
stability of the flight helmet might affect the in-flight postures of helicopter aircrew because they do not need to change their neck postures to keep their eyes aligned with the NVG. This explanation is only a hypothesis because we did not observe or measure the postures of the aircrew members. Nevertheless, we believe that future studies investigating flight head postures and movements of helicopter crews should confirm a good and stable helmet fit.

**Strengths and limitations of the study**

Neck pain in military helicopter pilots and rear aircrew is a recognised problem, and several studies have investigated this issue [3;7;11]. The effect of ergonomic improvements in a real working situation, however, is seldom studied. To the best of our knowledge, this is the first study to evaluate an ergonomic intervention in real airborne flights. However, the strength of the current study, taking measurements immediately after real airborne flights, might at the same time have been the limitation of the study. We could not control for the type and duration of the flight, which might have affected the outcomes. We tried to equalise this variation within subjects between T1, T2 and T3 by taking the means of several flights per condition. The optimum number of flights is debatable; however, we had to consider the practical fulfilment of the study as well. Post hoc within-subject analyses revealed that the flight duration did not differ between T1 and T2, but average flight duration was found to be significantly longer at T3. However, because the assumption would be that longer flight duration is associated with higher neck load, and no change or a decrease in neck load, pain and discomfort was reported at T3, we believe that the higher flight duration at T3 might have suppressed the effects of the interventions rather than the opposite.

**Conclusions**

This study suggests that an optimised helmet fit increases helmet stability, reduces neck load and hot spots and increases overall helmet comfort during real airborne helicopter flights. The neck pain perceived with an optimised helmet fit is highly associated with the neck load experienced during flight. During night flights, less hotspots and higher overall helmet comfort are perceived, and both are highly associated with irritations / distractions during flight. These results demonstrate the importance of achieving an optimised helmet fit for military helicopter aircrew and that an optimised helmet fit might have implications for both health and safety concerns.
References

General Discussion
Chapter 9
Prevention of flight-related neck pain in military aircrew
The main objective of this thesis was to study neck pain in military aircrew especially of the Royal Netherlands Air Force (RNLAF). The purpose of the studies performed in this thesis was to generate knowledge about the extent of the problem and identify associated factors concerning the work exposures and the aircrew’s capacity and to learn about aircrew’s experiences to identify feasible preventive measures. Based on the type of aircraft flown and the corresponding tasks to be performed, the aircrew was divided into the following three different occupational populations: the F-16 pilots, the helicopter pilots and the helicopter rear aircrew members. Aircrew members flying other fixed wing aircrafts of the RNLAF than the F-16 were excluded from this thesis.

In this chapter, the main research findings of this thesis are presented by answering the research questions as formulated in Chapter 1 followed by the interpretations of these findings and methodological considerations. Recommendations for future research and practice are presented at the end of this chapter.

Main findings

1. What is the prevalence of flight-related neck pain in military aircrew?
   
   **F-16 pilots**
   
   The overall one-year prevalence of any neck pain in F-16 pilots of the Royal Netherlands Air Force and the Belgian Air Force was 42%, and a total of 19% of the participating F-16 pilots experienced more than two episodes of neck pain which lasted for at least one day in the previous year. Of this latter group 77% indicated their complaints were flight-related.

   **Helicopter pilots and rear aircrew**
   
   The one-year prevalence estimates of any neck pain of the helicopter aircrew population of the Dutch Defence Helicopter Command\(^1\) were 43% in the helicopter pilot population and 62% in the rear aircrew population. Regular or continuous neck pain was reported by 20% of the pilots and by 28% of the rear aircrew members (Chapter 4 and 5). Over 90% of the pilots and rear aircrew members reporting regular or continuous neck pain attributed their complaints to flying. Almost half of the pilots with neck pain related their complaints to the use of night vision goggles.

2. What aspects of the aircrew members’ capacity and which work factors are associated with flight-related neck pain?
   
   **F-16 pilots**
   
   The pilots who experienced more than two episodes of neck pain which lasted for at least one day in the previous year reported significantly more often that their work...

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\(^1\) The Defence Helicopter Command of the Royal Netherlands Air Force include all land and sea tasked helicopter units of the Defence Organisation
demanded high forces, that they hold their neck in a forward bent position and had to sit for a long time compared to the pilots without these complaints. The pilots with neck pain reported significantly more hours of computer work per day. Flying hours were not significantly associated with neck pain. Considering the responses to work exposures, being physically and mentally tired at the end of the workday were significantly more often reported by pilots with neck pain compared to their colleagues without neck pain (Chapter 2). Regarding the F-16 pilot’s capacity (Chapter 3), the physical abilities of the neck of the F-16 pilots were measured by assessing the cervical range of motion, the neck position sense and the neck muscle strength. The F-16 pilots reporting regular or continuous neck pain had a decreased cervical range of motion in the sagittal and transversal plane compared to their colleagues without such complaints.

**Helicopter pilots and rear aircrew**
The pilots reporting regular or continuous neck pain reported significantly more total flying hours and flying hours in the previous year compared to their colleagues without these complaints. The type of helicopter flown or the flight helmet used was a work factor significantly associated with having regular or continuous neck pain. Considering the worker’s characteristics, female gender and older age were significantly associated with neck pain. Furthermore a higher frequency of previous history of neck pain, a higher prevalence of shoulder and thoracic pain in the previous 12 months, and being physically fatigue at the end of the workday were significantly more often reported by the pilots with neck pain (Chapter 4). The experienced neck load during flight was significantly highly correlated with the experienced neck pain during flight (Chapter 8). Regarding the pilots’ and rear aircrew members’ capacity (Chapter 6), the physical abilities of the neck assessed as the cervical range of motion, the position sense and strength were not different, neither between the pilots and rear aircrew members nor between the pilots and rear aircrew members with neck pain compared to their colleagues without neck pain and no interaction effect between occupation (pilot/rear aircrew) and neck pain status (neck pain/no neck pain) was found.

**3. Can an optimised helmet fit reduce the neck load and pain during flight in helicopter aircrew?**
A common work factor of both helicopter pilots and rear aircrew members was the head equipment and often making dynamic movements with their necks (Chapter 5). Exploring the experiences of the helicopter pilots and rear aircrew members revealed that the stability of the head equipment, the fit of the helmet and the comfort of the helmet were related to the experienced neck load during flight (Chapter 7). Based on these results, an intervention was developed and tested that aimed to optimise the fit of the aircrew’s helmet and sought to improve the stability of the helmet while taking comfort into account (Chapter 8). The evaluation of applying an optimised helmet fit resulted in a significant decrease in the experienced neck load and a trend in decreased
neck pain during flight. In addition, the optimised helmet fit resulted in a significant
decrease in helmet gliding (increase of helmet stability) and a decreased experience of
pressure points, a trend in decreased experienced irritation/distraction and a significant
increase in the experienced overall helmet comfort during flight.

**Interpretations of findings**

**Neck pain prevalence**
The estimates of the one-year prevalence of regular or continuous neck pain in F16-
pilots, helicopter pilots and helicopter rear aircrew members were 19%, 20% and 28%,
respectively. These estimates of the neck pain prevalence are similar to those of the
Dutch non-flying working population [28]. This would suggest that military pilots
and rear aircrew members are at no greater risk for developing neck pain than the
non-flying working population. However, military aircrew of the RNLAF are a selected
population; they have to meet medical and physical standards before entering flying
school and undergo yearly medical examinations. They therefore are assumed to be a
population in better physical condition than the average worker. From this perspective,
a lower prevalence of neck pain would be expected, and these similar prevalence
estimates could thus indicate a relatively higher risk for neck pain among military
aircrew. An explanation for this higher risk may be sought in the specific work demands
of military aircrew compared to the general working population. In the helicopter pilots
population, this explanation was strengthened by the result that more flying hours were
reported by the pilots with neck pain compared to their colleagues without regular
or continuous neck pain. In addition to the health concern, in other studies, military
pilots have reported that their neck pain interfered with their flying performance and
duty, which makes neck pain not only a health concern but also a safety and operational
concern [2;9;26]. Given the neck pain prevalence found, the perceived relationship of
neck complaints to flying, and the consequences of pain on flying performance and
duty reported in the literature, we consider neck pain in the military aircrew of the
RNLAF to be a work-related complaint that should be prevented whenever possible.

**Towards prevention**

**Improving physical capacity?**
Initially, the strategy chosen towards the prevention of flight-related neck pain was
to develop a physical training intervention program to improve the physical capacity.
Interventions targeted at lowering the work exposures were believed to be infeasible
because of the operational demands and regulations accompanying military flying. In
addition, cockpit and cabin ergonomics in military aircrafts is unfortunately not very
open to change, and many of the aircrafts will remain operational for many years in the
future. The focus in preventing neck pain is therefore necessarily on the individual. To
develop a physical training intervention program as a preventive measure for flight-related neck pain, the possible impairments of the physical abilities of pilots and rear aircrew with neck pain should first be identified. We measured the active cervical range of motion, the position sense and maximum isometric muscle strength, which are three tests often used in the clinical setting to assess neck pain [21]. According to the literature, the high demands on muscle strength during flight and the pilots’ lack of muscular force of the cervical musculature could be the main risk factors causing neck pain [3;22]. As a consequence, neck strengthening exercises are often recommended in the prevention of neck complaints in fighter pilots [1;4;11;19]. However, in our study (Chapter 3) there were no significant differences between healthy pilots and those with neck pain concerning neck muscle strength. Furthermore, pilots who actually performed neck exercises were equally represented in the group with and without neck pain (Chapter 2). Additionally, Newman [20] could not show any differences in pain prevalence between pilots who performed neck strength exercises and those who did not. These results suggest neck strength training to reduce or prevent neck pain in F-16 pilots as suggested by others might not result in the desired effect. The F-16 pilots with neck pain had a smaller cervical range of motion in the sagittal and transverse plane. Smaller cervical range of motion in the sagittal and transverse plane have been reported in other populations with neck pain [6;10;14;25]. The reason for the smaller cervical range of motion in the neck pain group remains unknown. It has been suggested that a reduced active range of motion in subjects with ongoing neck pain could be expected to relate to fear avoidance, but Ang [4] did not find such relation in military pilots. Other suggestions for a smaller cervical range of motion may be that the decrease might be caused by shortened neck musculature or degenerative changes brought on by flying as in fighter pilots premature degeneration of the cervical spine has been described [23]. Based on our results, training programs to maintain a proper active cervical range of motion might reduce neck pain, but further studies should investigate the reason for a smaller cervical range of motion in fighter pilots and the effectiveness of this type of training program.

We did not find any significant differences in neck muscle strength, neck position sense, or active cervical range of motion between helicopter pilots and rear aircrew or between the pilots and rear aircrew with neck pain and their colleagues without neck pain. To the best of our knowledge, we were the first to compare physical abilities of the neck between pilots and rear aircrew. Our results are in line with a recently performed study by Harrison et al. [16], who did not find any differences in physical abilities between pilots and rear aircrew. Our results suggest that these physical abilities, as assessed in this study are not associated with neck pain in these occupational populations. Some caution is required, however, because the results for the neck strength variables and range of motion variables were always somewhat higher in the pilots and the rear aircrew without neck pain compared to their colleagues with neck pain. The rather small number of pilots and rear aircrew members in the neck pain group might also
have been insufficient to demonstrate significant differences (see methodological considerations). We used three measurements of physical abilities often used in the practice of civilian physiotherapy, and deficits in these abilities have been found in the non-flying population with non-specific neck pain. However, other muscle function mechanisms may play parts in the occurrence of flight-related neck pain. Muscle fatigue, for example was not assessed, although it might play an important role in flight-related neck pain in helicopter pilots, as suggested by others [3;17;18], especially because helicopter flights of 6 to 8 hours are no longer the exception in the RNLAF. It would be interesting to investigate which physical abilities are mainly applicable to in-flight abilities and test these abilities. Referring to the conceptual model of work-relatedness of musculoskeletal complaints (Chapter 1), the mismatch between the physical job requirements and the physical capacity of the worker could be a risk factor for developing work-related neck pain. To validate this hypothesis, the physical requirements of flying should first be assessed, and then they should be compared to the physical capacities of the aircrew members. Further research to measure the in-flight physical requirements of the neck by assessing the in-flight exposures through observations or direct measurements is highly recommended [24;29].

At the same time as the research was carried out for this thesis, Swedish researchers [5] were performing a clinical trial to investigate the preventive efficacy of a neck/shoulder exercise regimen in helicopter pilots on neck pain. The exercises emphasised neck/shoulder movement control and included endurance-strength exercises. The exercise group had a significant reduction in neck pain cases compared to controls at the 12-month follow-up, rated for the previous week and the previous 3 months. Neck training programs may thus be effective in the helicopter pilot population to reduce cases with neck pain. It would be interesting to study whether movement control and endurance-strength are key abilities during flight for helicopter pilots and rear aircrew members.

Our results showed good physical capacities among the helicopter aircrew as assessed in this study. Further research into the required in-flight abilities and the effectiveness of job specific physical training is recommended.

An optimised helmet fit
In addition to differences in work demands between helicopter pilots and rear aircrew, there are also common factors that might be risk factors of flight-induced neck pain. A potential common factor includes the head equipment that is worn and the exposure to dynamic neck movements during flight (Chapter 5). An intervention involving modifications to the flight helmet could therefore be beneficial to both pilots and rear aircrew members. We used the experiences of the pilots and rear aircrew by interviewing them following structured qualitative analyses [8;13] to identify the factors related to the experienced neck load during flight resulting from their head equipment. In line with what would have been expected from a biomechanical point
of view [15;27], factors such as weight and weight distribution of the flight helmet with mounted equipment were identified as factors related to the aircrew’s neck load. However, three other factors, namely the stability of the helmet, the helmet fit and the comfort of the helmet were also identified as factors related to the in-flight neck load and had, to the best of our knowledge, never before been taken into account in studies investigating neck load in military aircrew. Furthermore, the results from the qualitative study revealed the possible reasons for not achieving a stable and comfortable helmet, and based on these results, an intervention could be developed. The intervention of an optimised helmet fit that followed showed a decrease in the experienced neck load during flight. According to the conceptual model describing the work-relatedness of musculoskeletal complaints (Chapter 1), this short-term response indicates potential for this intervention to prevent flight-related neck pain in the longer term. Furthermore the optimised helmet fit resulted in increased comfort during flight and comfort was significantly negatively associated with irritation and distraction during the flight. Thus, in addition to the potential of the intervention to reduce flight-induced neck pain, the intervention of an optimised helmet fit seems to have positive effect on flying performance and duty.

Methodological considerations

In this section, methodological issues are addressed, as well as the strengths and weakness of the study designs, the study population and the outcome measures used. Concerning the study population, a strength of the studies as described in Chapters 2 to 6 is that the intention was to include the whole population of F-16 pilots, helicopter pilots and rear aircrew members who were on active flight status. Only pilots and rear aircrew members who were on military deployment, holiday or sick leave were not included during recruitment. The response rate of the pilots and rear aircrew present at the days the questionnaire and physical tests were administered, was nearly 100%. In total, 70-80% of the F-16 pilots and helicopter aircrew members were reached and participated. In terms of external validity, the main findings can be used in other air forces flying the same types of aircrafts and using the same head equipment. Demographics of personnel and total number of flying hours were similar to other international studies investigating military aircrew [2;16;26]. The main findings could also be of interest for other populations flying similar aircrafts and also using night vision goggles, e.g. the police forces.

In the questionnaire studies, univariate statistical methods were used, multiple outcome measures were tested and several significant outcomes were found. Some researchers argue that the finding of a significant outcome by chance is increased when multiple test are performed and that the p-value should be adjusted to reduce this chance. The need for adjusted p-values when multiple comparisons are made is debatable
because while the p-value adjustments may reduce the chance of making type I errors, they increase the chance of making type II errors and thus still may lead to incorrect conclusions. Several strategies are suggested in literature to address this complex multiplicity problem [7;12]. For the questionnaire study of the F-16 pilots, we did not adjust the p-value and tested the complete questionnaire for differences in pilots with and without neck pain. This led to numerous significance tests and might be seen as a limitation of that study. However, for the questionnaire study of the helicopter pilots and for the other studies that followed and in which multiple testing was applied, we used the strategy to carefully select the outcome measures based on previous research and the hypothesis for each variable, and we discussed each significant outcome with respect to the other outcomes and possible confounding variables. Because there was a hypothesis for each outcome measure, a p-value for each test could be set and did not need to be adjusted [12]. Furthermore the focus of the different studies of this thesis was not solely on statistical significance, but on describing outcomes and discussing their relevance, which is seen as a strength of these studies.

The outcome measure in the studies described in Chapters 2 to 6 was self-reported neck pain in the previous year and was defined as any pain, including aches and discomfort with a diagram used to illustrate and define the specific neck area. Allocation to the neck pain group or the reference group was based on the responses of the neck pain question as follows: never, occasional, regular or continuous. The reference group in the studies described in Chapters 2 to 4 experienced never or occasionally neck pain in the previous year, while the neck pain group experienced regular or continuous neck pain. Many self-assessment questionnaires exist that address perceived pain and disability and overall self-reports of neck pain have been found to be reliable and valid [21]. We did not use other criteria to allocate the pilots and rear aircrew members into the neck pain group, such as severity of complaints or self-reports of functionality and disability. All participating aircrew members were on active flight status and thus fit to fly. Post hoc it was found that the great majority of the helicopter group reporting regular and continuous neck pain attributed their neck pain to flying compared to only a small proportion of the aircrew members reporting occasional neck pain. This strengthens our belief of having the true flight-related neck pain cases in the neck pain group for the purposes of this thesis, which was to study flight related neck pain for preventive purposes.

It still might be argued whether the contrast between the neck pain group and the reference group was distinctive enough. We considered the division into groups (neck pain versus reference) before the analyses and did not know what the distribution would be of the aircrew population on the four answer possibilities. With the knowledge of the questionnaire studies about this distribution, we decided for the study assessing the physical abilities in the helicopter population to exclude the aircrew members reporting only occasional neck pain to create as much contrast as possible between the groups. No significant differences were found although on average there was a trend
towards lower values in strength and cervical range of motion in the pilots and rear aircrew members with neck pain compared to their colleagues without neck pain. The number of participants in the neck pain group could have been too limited to reach statistical significance, or the contrast between the aircrew with and without neck pain was still too low. As mentioned before all aircrew were on active flight status and fit to fly. Differences in capacities might not have been detectable in this small population with this health status.

A strong study design to explore the experiences of both the pilots and rear aircrew members regarding factors related to the neck load resulting from their head equipment, was used in chapter 7, namely qualitative research methods. By using semi-structured interviews we were able to ask more in-depth questions about their experiences, compared to structured surveys or interviews. By using this method, we were able not only to identify the factors related to their experienced neck load but also to identify the reasons why a stable and comfortable helmet fit was not easily achieved. Using the aircrew’s input for the purpose of finding feasible preventive measures for flight-related neck pain is seen as a valuable strategy.

Several considerations led to the use of a within subject design in Chapter 8. The optimised helmet fit was developed for one helmet type, so only pilots and rear aircrew flying with this type were eligible to participate. This was approximately half of the total helicopter aircrew population. Pilots and rear aircrew were expected to fly at least nine flights using night vision goggles within a period of 3 months during October 2010-March 2011, and they had to be in the Netherlands as the executions of the optimised helmet fit could only take place in the Netherlands. These criteria were responsible for the number of eligible aircrew members, because of which a within-subject design was considered to be the most powerful. Furthermore, the extra value of including a control group in case more aircrew members would have been eligible to participate was rejected before recruitment started. Contamination effects would have been too serious of a risk because the pilots and rear aircrew members work at the same workplace, talk each other daily and regularly fly together.

**Recommendations**

**Recommendations for research**

The results of the qualitative study described in Chapter 7 revealed the following six factors that, according to the aircrew, were related to the experienced neck load during flight: the type of flight operation, the weight of the head equipment, the weight distribution of the head equipment, the stability of the helmet, the helmet fit and the comfort of the helmet. An intervention was developed based on these latter three factors. The results of this thesis show that an optimised helmet fit reduces the experienced neck load during night flights and that the experienced neck load is highly
associated with the experienced neck pain. Whether this short-term response may have a preventive effect on neck pain in the longer term was not investigated, and further research is needed to study this issue. There is also a need to further investigate the other three identified factors related to the experienced neck load. Counterweights are provided to aircrew to optimise the weight distribution of their head equipment, but the optimal weight and location of the counterweight on the helmet with respect to neck load is still unknown. There is a need for biomechanical studies that address this issue, and they should take the head and neck positions and movements during flight of both pilots and rear aircrew members into account. Therefore, there is also a need for the assessments of head and neck positions and movements during real flights. Furthermore, according to the results in this thesis, the different type of helicopter operations (e.g., navigation flight, slings and slopes) should be considered in these assessments, because rear aircrew members mentioned that their experienced neck load depended on the type of flight operation. These assessments could further provide important information about the physical abilities needed during flight and further studies could investigate whether these physical abilities meet the physical capacities of the pilots and rear aircrew members. The latter would contribute to a better understanding of the aetiology of flight-related neck pain.

**Recommendations for practice**

**Employees and employer**

An optimised helmet fit should be provided to all pilots and rear aircrew members. The protocol tested in this thesis was developed for one helmet type. Protocols to achieve an optimised helmet fit should be developed and applied for the other helmet types in use with the RNLAF. The flight equipment technicians who are responsible for the helmets fits need to be educated in how to perform these fits according to the protocol. Additionally, the pilots and rear aircrew members should be educated about the importance of an optimal helmet fit for both health and safety concerns and about the factors that determine an optimal fit. Pilots and rear aircrew members at the start of their career often do not know how and why their helmet is supposed to fit. They need to be informed when checks and adjustments of their helmets are needed.

As mentioned, the focus in preventing neck pain is necessarily on the individual, because cockpit and cabin ergonomics are not very open to change. However, in the long term, ergonomics in the military aircraft should receive more attention and the RNLAF should make ergonomic requirements important in their contracts with contractors for new aircrafts, aircraft interiors and flight equipment.

**Flight physician and ergonomist**

All pilots and rear aircrew members undergo medical examination on a yearly basis by flight physicians. Knowledge about the factors and symptoms that differ between aircrew members with and without neck pain is important to the flight physician. He
can recognise these factors and intervene as early as possible to prevent chronic work-related complaints.

Using semi-structured interviews to explore the experiences of the aircrew with respect to their experienced neck load during flight was considered to be a very valuable method in our search to preventive measures. This method is therefore recommended to other ergonomists in their search for other preventive interventions for work-related health complaints.

**Industry**
The flight helmet and night vision goggles in use by the RNLAF are two different systems made by different industries. A secondary aim of the qualitative study was to elucidate the factors contributing to an ideal flight helmet. Based on the results of that study, it is recommended that the industry consider the head equipment as one system in stead of separate systems. Furthermore, factors such as weight, weight distribution, helmet stability, helmet fit and comfort issues should be considered in head equipment designs and requirements. Depending on the helmet type and manufacturer, helmets come in a limited number of sizes. Every head is shaped differently, and the development of custom-made helmets is encouraged.
References


Summary
Prevention of flight-related neck pain in military aircrew
Neck pain is a common musculoskeletal complaint in both the general and working populations. Several studies have suggested a relationship between neck pain and certain occupational exposures, and specific occupations have been associated with the risk of neck pain. Military pilots and rear aircrew members are occupations with several occupational exposures that might cause neck pain. In addition to the negative impact of neck pain on health, safety might be one of the main concerns for the military aviation because neck pain may interfere with flying performance. It might be obvious that for both employees and employers it is important to prevent flight-related neck pain. Before proposing an intervention that might be effective in the prevention or alleviation of neck pain in military aircrew, it is important to gain insight in its work-relatedness. However, because of the operational demands and regulations that come with military flying, interventions targeting work exposures are thought to be less feasible and have therefore seldom been proposed or studied. In addition, cockpit and cabin ergonomics in military aircrafts are not easily modified, and many of the aircrafts will remain operational for many years. Therefore, the focus of this thesis in preventing neck pain is on the individual. Some aircrew members develop neck pain and others do not, and it is important to identify the factors that characterise aircrew with and without neck pain. Furthermore, the experiences of the aircrew could provide important information in the development of interventions aimed at the prevention of work-related neck pain.

The main objective of this thesis is to study neck pain in military aircrew especially of the Royal Netherlands Air Force (RNLAF) and, in doing so, to generate knowledge regarding the extent of the problem, to identify associated factors concerning the aircrew’s capacity and work situation, and to learn about aircrew’s experiences in order to find and test feasible preventive measures.

The research questions are as follows:

1. What is the prevalence of flight-related neck pain in military aircrew?
2. What aspects of the aircrew members’ capacity and which work factors are associated with flight-related neck pain?
3. Can an optimised helmet fit reduce the neck load and pain during flight in helicopter aircrew?

The studies described in Chapters 2 and 3 represent a collaboration with the Belgian Air Forces (BAF) and address the first two research questions among F-16 pilots. Chapters 4 to 8 address all three research questions among the helicopter population (pilots and rear aircrew members) of the RNLAF.
To answer the first two research questions, all F-16 squadrons of the RNLAF and BAF and all helicopter squadrons of the Defence Helicopter Command\(^1\) (DHC) were visited by the research team on three to four consecutive days depending on the availability of the pilots and the rear aircrew members. Approximately 70% of the F-16 pilot population, 75% of the helicopter pilot population, and 80% of the helicopter rear aircrew population was reached. A questionnaire assessing individual characteristics, health-related issues, and work exposures and responses including flightlog information on work-related flight hours was administered. The physical capacity of the neck was assessed by measuring the active cervical range of motion (flexion-extension, right-left rotation, and right-left lateral flexion), the neck position sense (reposition error back to neutral and defined positions after submaximal cervical movement) and the maximal isometric neck strength (flexion, extension and right and left lateral flexion). Almost all pilots and rear aircrew members who were present in this period participated (96% response rate), and all were on active flying duty. The results of the questionnaire and physical tests are presented in Chapters 2 to 6.

Chapters 2 and 3 address the first two research questions among F-16 pilots. In Chapter 2, the self-reported one-year prevalence of neck pain was estimated, and the individual characteristics and work- and health-related factors of F-16 pilots with and without neck pain were compared. There were 90 male F-16 pilots of the RNLAF and BAF who voluntarily completed the anonymous questionnaire. The reported one-year prevalence of any neck pain was 42%, and 19% experienced more than two episodes of neck pain that lasted for at least one day. Among the latter group, 77% indicated that their complaints were flight-related. Pilots were divided into the following two groups: a neck pain group (n=17) and a reference group (n=73). The neck pain group contained pilots with more than two episodes of neck pain that lasted for at least one day during the previous year. No significant differences were found between the two groups in terms of the total flight hours, the hours flown with night vision goggles, and in the individual characteristics. High-force demands (p<0.01), often sitting for a long time (p=0.04), frequently holding the neck in a forward bent posture (p=0.01), and being physically tired (p<0.01) were the physical work-related factors that were significantly more often reported in the neck pain group. A greater number of hours of computer work per day (p=0.05) was reported by the neck pain group compared to the reference group. The neck pain group also reported significantly more often to be mentally tired at the end of the day (p=0.01) and being annoyed by others at the workplace (p<0.01). The results of this study suggest that both physical and psychosocial factors could be important factors in the development or maintenance of neck pain in F-16 pilots.

In Chapter 3, the results of the assessments of the physical neck abilities of the 90 F-16

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\(^1\) The Defence Helicopter Command of the Royal Netherlands Air Force includes all land and sea tasked helicopter units of the Defence Organisation.
pilots are given. There were no significant differences between the neck pain group (n=17) and the reference group (n=73) concerning neck muscle strength and neck position sense. Compared to the reference group, the neck pain group had a limited range of motion in the sagittal plane (p=0.01) and in the transverse plane (p=0.04). The suggestion that physical training programs might reduce neck pain is not established in this study. Further studies should investigate the effectiveness of this type of training program.

Flying an F-16 is not the same as flying a helicopter, and research into neck pain in military helicopter pilots lacked the understanding of associated factors. Chapter 4 addresses the first research question and part of the second research question among helicopter pilots. In Chapter 4, the self-reported one-year prevalence of neck pain in military helicopter pilots of the Defence Helicopter Command was assessed, and work-related, individual and health-related factors of the pilots with regular or continuous neck pain (neck pain group) were compared with these factors in pilots without these complaints (reference group) in the previous year. There were 103 male and 10 female helicopter pilots who completed the questionnaire. The reported one-year prevalence of any neck pain was 43% and 20% for regular or continuous neck pain, respectively. Over 90% of participants in the neck pain group attributed their pain to flying. In the neck pain group (n=22), significantly more total flying hours (p<0.01) as well as flying hours in the previous year (p=0.02) were reported compared to the reference group (n=91). The type of helicopter flown or the type of flight helmet used was a work-related factor that was significantly associated with neck pain (p=0.03). The mean hours flown with night vision goggles for the total group was 81; night vision goggle hours did not significantly differ between the neck pain group and the reference group. Older age (p<0.01), being female (p=0.02) (individual factors), being physical fatigued at the end of the work day (p=0.02), having a history of neck pain (p<0.01), as well as having pain in the shoulder (p=0.04) and upper back (p<0.01) (health-related factors) were all significantly more often reported in the neck pain group than in the reference group. The findings in this chapter suggest that neck pain in military helicopter pilots is a significant work-related complaint and may be a consequence of longer exposure to flying.

Helicopter pilots and rear aircrew members perform different tasks in the helicopter. The pilots work in the cockpit and fly the helicopter that, depending on the type and mission, is used to transport troops and cargo, perform search and rescue missions, and provide close combat support for ground troops. The rear aircrew members work in the cabin of the helicopter, and their main tasks include troop management, material handling, hoist operation, rescue, surveillance and clearance tasks, and sensor operation. Although pilots and rear aircrew members both have to address specific factors that come with military helicopter operations such as wearing heavy headgear
while performing their tasks, their tasks differ, the work environments within the helicopter (cockpit versus cabin) differ, and consequently, the physical loads differ. In Chapter 5, the one-year prevalence of neck pain in military helicopter rear aircrew members was estimated (first research question), and self-reported physical load was compared between pilots (n=113) and rear aircrew members (n=61). The one-year prevalence of neck pain among the rear aircrew members was 62% for any neck pain and 28% for regular or continuous neck pain, and 94% of the latter group attributed their neck pain to flying. Considering the exposures to physical load factors, significantly more rear aircrew members than pilots reported being often exposed to manual material handling (p<0.01), performing dynamic movements with their torsos (p<0.01), working in a prolonged bent or twisted posture with their torsos (p<0.01) or their necks (p<0.01), working with their arms raised (p<0.01), and working in awkward postures (p<0.01). Significantly more pilots than rear aircrew members reported often being exposed to prolonged work in the same position/posture during their job (p<0.01). Almost all pilots and rear aircrew members reported being often exposed to prolonged sitting and dynamic movements with their neck. These results suggest that rear aircrew members are more often exposed to a variety of physical loads compared to their colleagues who sit in the cockpit of the helicopter.

Chapter 6 addresses the second research question among the helicopter pilots and rear aircrew members. In Chapter 6, the results of the assessments of the physical abilities of the helicopter pilots and rear aircrew members are presented. The main purpose was to investigate the physical abilities of the neck in helicopter pilots and rear aircrew members with neck pain and to compare them to the physical abilities of pilots and rear aircrew members without neck pain. Furthermore, because pilots and rear aircrew members are exposed to a different variety of physical load factors, we hypothesised that a possible difference between the aircrew with neck pain compared to the aircrew without neck pain could be different for pilots compared to rear aircrew members. For the purposes of this study, pilots and rear aircrew who reported occasional neck pain in the previous year were excluded from the analysis in order to create as much contrast as possible between the groups. The study included 61 male helicopter pilots and 22 rear aircrew members without neck pain and 17 pilots and 17 rear aircrew members with neck pain. Two-way factorial analyses of variance were performed, in which the fixed factors were occupation (pilot or rear aircrew) and neck pain state (neck pain group or reference group). On average, there was a trend toward lower values in strength (extension: 55 (19) Nm vs. 58 (20) Nm; flexion: 22 (8) Nm vs. 24 (12) Nm) and smaller cervical range of motion (flexion-extension: 132 (19)° vs. 137 (15)°; rotation: 156 (14)° vs. 160 (14)°) in the total neck pain group compared to the reference group. However, the two-way factorial ANOVA revealed neither significant main effects nor significant interaction effects in any of the measured physical abilities. These results suggest that
having experienced neck pain was not significantly associated with differences in the physical abilities of the cervical spines of helicopter crew, as assessed in this study.

The results from Chapters 4 and 5 suggest that neck pain is a work-related complaint in both helicopter pilots and helicopter rear aircrew members. Although both occupations are exposed to a different variety of physical load factors that might be risk factors for developing neck pain, there are also some similarities. Both pilots and rear aircrew members are often exposed to dynamic movements with their neck, and they wear the same headgear. These results have implications for prevention, and modification of this headgear could be advantageous for both pilots and rear aircrew members. As a first step in trying to improve the ergonomic situation with respect to the headgear, it is important to know what the in-flight experiences of pilots and rear aircrew members are concerning their helmet configurations in relation to their experienced neck load. We interviewed 12 pilots and 11 rear aircrew members using semi-structured interviews (Chapter 7). The interviews were transcribed verbatim, and qualitative analyses were performed. Various factors as well as their interrelations and relation to experienced neck load emerged as the analysis progressed. Factors that were directly related to the experienced neck load were type of flight operations and tasks as well as the weight and the weight distribution of the flight helmet. Factors that indirectly contributed to the experienced neck load were the stability of the helmet, the helmet fit and the comfort of the helmet.

The next step in preventing flight-related neck pain in military helicopter pilots and rear aircrew members was to develop and test an intervention aiming to improve the helmet fit and the helmet stability, taking comfort into account (research question 3). The main purpose of the study in Chapter 8 was to improve the helmet fit of military helicopter aircrew members and evaluate its effect on the experienced neck load and neck pain, helmet stability (helmet gliding), hot spots (pressure points), irritation/distraction, and overall helmet comfort during night flights. A within-subject design was used over a three-month period that consisted of the following two consecutive interventions to optimise the fit of the aircrew’s helmets: 1) development of a new helmet fit using a renewed protocol and 2) replacement of a thermoplastic inner liner with a viscoelastic foam inner liner. The optimised helmet fit was evaluated during night flights because during the interviews (Chapter 7), pilots and rear aircrew members indicated that they experienced the most neck load during night flights and that they suffered the most from an unstable helmet when flying with night vision goggles attached to their helmets. A total of 18 pilots and rear aircrew members rated the outcome measures using Visual Analogue Scales immediately after their night flights, with a total of three night flights per measurement period. The optimised helmet fit resulted in a significant decrease in the experienced neck load (p=0.02), helmet gliding (p<0.01),
and pressure points (p<0.01), a decreased trend in the experienced neck pain (p=0.06) and irritation/distraction (p=0.06), and a significant increase in the experienced overall helmet comfort (p<0.01) during flight. These results demonstrate the importance of achieving an optimised helmet fit for military helicopter aircrew and that an optimised helmet fit might have implications for both health and safety concerns.

In Chapter 9, the main research findings are summarised and discussed, and recommendations for further research and practice are presented. A strength of the study was the intention to include the entire population of F-16 pilots, helicopter pilots and rear aircrew members and that 70-80% of potential participants were reached and ultimately participated. The one-year prevalence of regular or continuous neck pain in F-16 pilots, helicopter pilots and helicopter rear aircrew members was 19%, 20% and 28%, respectively, and over 75% of them reported their complaints to be flight-related (first research question). The division of the aircrew in the neck pain group and the reference group was based on self-reported neck pain. It was discussed in Chapter 9 whether these self-reports were a reliable and valid measure and whether the contrast between the two groups might have been distinctive enough for the analysis to answer the second research question. Based on the literature and the fact that more than 75% of the pilots and rear aircrew members attributed their neck pain to flying, we concluded that this outcome measure was reliable and valid. Concerning the second research question, several individual, health- and work-related factors that have previously been associated with neck pain in the general working population were also associated with neck pain in this specific occupational population of military pilots and rear aircrew members. The helicopter pilots in the neck pain group reported significantly more flying hours compared to their colleagues in the reference group, suggesting that their neck pain may be a consequence of longer exposure to flying. The experienced neck load during flight was significantly and highly correlated to the experienced neck pain during helicopter flights. F-16 pilots in the neck pain group had a smaller range of motion compared to the reference group. No differences were found in strength, cervical range of motion or neck position sense between helicopter pilots and rear aircrew members in the neck pain group compared to their colleagues in the reference group. It was discussed in Chapter 9 whether the physical abilities as assessed in this study represent the critical abilities required during flight. For example, muscle fatigue was not assessed, although it might play an important role in flight-related neck pain, especially because helicopter flights of 6 to 8 hours are now common.

Factors that were identified to be related to the experienced neck load during flight were the type of flight operation, the weight and the weight distribution, the stability of the headgear, and the fit and comfort of the helmet. An optimised helmet fit resulted in a more stable and comfortable helmet fit and decreased the experienced neck load during flight (third research question).
These findings lead to the recommendation that an optimised helmet fit should be provided to all pilots and rear aircrew members. Recommendations for further research include the study of the weight and the weight distribution of the headgear with respect to neck load, taking the in-flight head and neck positions and movements into account. There is a need to assess the in-flight exposures in more detail, and these assessments could provide information about the physical abilities required during flight. The industry is encouraged to develop custom-made flight helmets.
Prevention of flight-related neck pain in military aircrew
Samenvatting
Prevention of flight-related neck pain in military aircrew

Militaire luchtvarenden die in de cockpit werken (vliegers) en luchtvarenden die achter in de helikopter werken worden bij het uitoefenen van hun beroep blootgesteld aan specifieke factoren met mogelijk een verhoogd risico op het krijgen van nekpijn. Naast de consequenties van nekpijn voor de gezondheid van de militaire luchtvarenden, zijn de consequenties voor de vliegveiligheid een punt van zorg voor de militaire luchtvaart. Militaire vliegers hebben in eerder onderzoek laten weten dat hun nekpijn invloed heeft op hun vliegprestaties en dat ze vanwege nekpijn vluchten soms eerder afbreken, omdat ze het niet verantwoord vinden om verder te vliegen. Het is dus zowel voor de gezondheid van de militaire luchtvarenden als voor het behouden van de vliegveiligheid van belang om nekpijn te voorkomen.

Om maatregelen te kunnen treffen om nekpijn te voorkomen, is eerst inzicht nodig in de relatie tussen het krijgen en onderhouden van nekpijn en het militaire vliegen. Verschillende factoren binnen het militaire vliegen kunnen hierin een rol spelen, zoals blootstaan aan G-krachten, trillingen, ongunstige werkhoudingen en het dragen van de helm met daaraan bevestigde uitrusting zoals nachtkijkers. Vanwege operationele eisen en regelgeving waarmee de militaire luchtvaart te maken heeft, is het niet eenvoudig om de blootstelling aan risicovolle factoren voor het ontwikkelen van nekpijn te verminderen. Omdat vliegers en luchtvarenden die achter in de helikopter werken hun vaardigheden moeten onderhouden, is een vermindering van vlieguren niet wenselijk. De ergonomie van een cockpit of cabine wordt bij de ontwikkeling van het luchtvaartuig vastgelegd en hierin kan na aanschaf weinig worden veranderd. Maatregelen om vliegerelateerde nekpijn te voorkomen of te verminderen zijn daarom vooral gericht op de individuele luchtvarende. Sommige militaire luchtvarenden krijgen nekpijn en anderen niet. Het is belangrijk om te achterhalen of er verschillen bestaan tussen militaire luchtvarenden met nekpijn vergeleken met hun collega’s die geen nekpijn krijgen. Hebben militaire luchtvarenden zonder nekpijn bijvoorbeeld meer spierkracht in hun nek? Dan zou een trainingsprogramma gericht op het verbeteren van de spierkracht mogelijk nekpijn kunnen voorkomen. Een andere mogelijkheid voor het voorkomen van nekpijn zijn aanpassingen aan de helm, die met alle toebehoren een belasting voor de nek vormt.
Het doel van de onderzoeken in dit proefschrift is kennis te verkrijgen over nekpijn bij de militaire luchtvarenden. De volgende onderzoeksvragen zijn onderzocht:
1 Hoe vaak komt nekpijn voor bij militaire luchtvarenden?
2 Welke eigenschappen van militaire luchtvarenden en welke factoren in hun werk houden verband met nekpijn?
3 Kan het optimaliseren van de pasvorm van de vliegerhelm de nekbelasting en nekpijn tijdens de helikoptervlucht verminderen?

In dit proefschrift zijn drie groepen luchtvarenden onderzocht, te weten: de F-16 vliegers, de helikoptervliegers, en de luchtvarenden die achter in de helikopters werken. Voor de F-16 vliegers is antwoord gegeven op de eerste twee onderzoeksvragen en hiervoor is samengewerkt met de Belgische Luchtmacht. Voor de helikoptervliegers en luchtvarenden die achter in de helikopter werken komen alle drie de onderzoeksvragen aan bod in dit proefschrift.

Voor het beantwoorden van de eerste twee onderzoeksvragen is een vragenlijstonderzoek uitgevoerd en is het functioneren van de nek gemeten. De vragenlijst bestond uit vragen over individuele eigenschappen, gezondheidsgerelateerde factoren en werkgerelateerde factoren, zoals onder andere het aantal geregistreerde vlieguren. Het functioneren van de nek is gemeten door het bepalen van: 1) de maximale bewegingsuitslag van de nek tijdens voor- en achterover buigen (flexie-extensie), draaien (links-rechts rotatie) en zijwaarts bewegen van de nek (links-rechts lateroflexie); 2) de maximale isometrische kracht van de nekspieren verantwoordelijk voor het buigen, strekken en zijwaarts bewegen van de nek (kracht van de flexoren, extensoren en lateroflexoren van de nek); 3) de positiezin van de nek (proprioceptie), dit is het vermogen om de positie van het eigen hoofd op de nek waar te nemen en werd gemeten door het verschil in positie te meten na een submaximale draai- en buigbeweging van de nek. Het onderzoeksteam heeft alle F-16 squadrons van de Nederlandse en Belgische luchtmacht en alle helikopter squadronen van het Defensie Helikopter Commando\(^1\) bezocht en de vragenlijsten en functionele testen afgenomen. Hiermee werd 70% tot 80% van de populatie F-16 vliegers, helikoptervliegers en luchtvarenden die achter in de helikopter werken bereikt en bijna 100% van hen die aanwezig waren hebben deelgenomen aan dit onderzoek. Dit waren in totaal 90 F-16 vliegers, 113 helikoptervliegers en 61 luchtvarenden die achter in de helikopter werken.

\(^1\) Alle helikopters van defensie zijn ingedeeld bij het Defensie Helikopter Commando (DHC). Dit betreft de gevechtsbelikopters, de transport helikopters, de maritieme helikopters en de search- & rescue helikopters. Het DHC valt onder de Koninklijke Luchtmacht.
Samenvatting

Hoe vaak komt nekpijn voor bij militaire luchtvarenden?
Van de F-16 vliegers geeft 42% aan ten minste een keer nekpijn te hebben gehad in het afgelopen jaar. In totaal geeft 19% van de F-16 vliegers aan het afgelopen jaar meer dan tweemaal nekpijn te hebben gehad waarbij de pijn ten minste een dag aanhield. Van deze laatste groep geeft 77% aan dat hun pijnklachten zijn ontstaan door het vliegen met de F-16 (hoofdstuk 2).

Bij de helikopter luchtvarenden geeft 43% van de vliegers (hoofdstuk 4) en 62% van de luchtvarenden die achter in de helikopter werken (hoofdstuk 5) aan het afgelopen jaar last te hebben gehad van hun nek. Van de vliegers geeft 20% aan het afgelopen jaar regelmatig of aanhoudende nekpijn te hebben gehad en bij de luchtvarenden die achter in de helikopter werken is dit 28%. Meer dan 90% van de vliegers en de luchtvarenden die achter in de helikopter werken en die regelmatig of aanhoudende pijnklachten hebben relateren hun klachten aan het vliegen.

Welke eigenschappen van militaire luchtvarenden en welke factoren in hun werk houden verband met nekpijn?
De F-16 vliegers (hoofdstuk 2) met meer dan tweemaal nekpijn in het afgelopen jaar (nekpijn groep) worden vergeleken met hun collega’s zonder deze klachten (referentie groep). De nekpijn groep geeft vaker aan dat het werk hen veel kracht kost, dat zij hun nek in een voorovergebogen houding moeten houden en dat ze gedurende lange periodes moeten zitten. Ook geven de vliegers van de nekpijn groep aan meer tijd achter de computer door te brengen voor hun werk. Het totale aantal vlieguren en de vlieguren die de vliegers met nachtkijkers hebben gevlogen, verschillen niet tussen de nekpijn groep en de referentiegroep. De groep met nekpijn geeft vaker aan fysiek en mentaal moe te zijn aan het einde van een werkdag dan de referentiegroep. Ook geven de vliegers met nekpijn vaker aan geïrriteerd te zijn door hun collega’s dan de vliegers zonder nekpijn.

In hoofdstuk 3 wordt gekeken naar de functionaliteit van de nek en ook hier worden de uitkomsten vergeleken van de groep F-16 vliegers met nekpijn en de vliegers van de referentiegroep. Zowel ten aanzien van maximale spierkracht als van de positiezin is geen verschil gevonden. Wel hadden de vliegers van de nekpijn groep zowel bij het voor- en achterover buigen van hun nek als bij het draaien van hun nek een kleinere bewegingsuitslag dan de vliegers van de referentiegroep.

In hoofdstuk 4 worden de helikoptervliegers onderzocht waarbij de groep met nekpijn wordt vergeleken met de groep zonder klachten. De vliegers met regelmatig of aanhoudende nekpijn (nekpijn groep) hebben in totaal meer vlieguren gemaakt dan hun collega’s zonder deze klachten (referentie groep). Ook hebben zij in het afgelopen jaar meer gevlogen. Voor helikoptervliegers van het Defensie Helikopter Commando bestaan er drie typen vliegerhelmen en het type helikopter waarin men vliegt, bepaalt welke vliegerhelm wordt gedragen. Het hebben van nekklachten kwam vaker voor bij de vliegers die vliegen met het ene type helm dan bij de vliegers die vliegen met de andere
typesp. helm. Verder komt regulierlijke of aanhoudende nekpijn vaker voor bij vrouwen dan bij mannen en ook vaker bij de hogere leeftijdsgroep. Bij de vliegers in de nekpijn groep is vergeleken met hun collega’s in de referentiegroep een hogere frequentie van eerdere episodes van nekpijn gemeld en komt pijn in de schouders en de bovenrug vaker voor. Ook geven de vliegers in de nekpijn groep vaker aan fysiek vermoeid te zijn aan het einde van de werkdag.

In het onderzoek beschreven in hoofdstuk 6 wordt onderzocht of helikoptervliegers en luchtvarenden die achter in de helikopter werken met en zonder regulierlijke of aanhoudende nekpijn verschillend scoren op de verschillende functionele testen van de nek. Omdat helikoptervliegers en luchtvarenden die achter in de helikopter werken aan verschillende fysiek belastende factoren worden blootgesteld tijdens hun werk, is ook gekeken of er verschillen waren tussen de hele groep vliegers (zowel met als zonder klachten) en de hele groep luchtvarenden die achter in de helikopter werken (zowel met als zonder klachten). De helikoptervliegers en luchtvarenden die achter in de helikopter werken met regulierlijke en aanhoudende nekpijn scoren niet verschillend op maximale kracht en maximale bewegingsuitslag vergeleken met hun collega’s zonder nekpijn. Ook ten aanzien van positiezin zijn geen verschillen gevonden. Tussen de hele groep vliegers en de hele groep luchtvarenden die achter in de helikopter werken zijn ook geen verschillen gevonden.

Op weg naar preventie van nekpijn

In hoofdstuk 5 worden de fysiek belastende factoren vergeleken tussen de vliegers en de luchtvarenden die achter in de helikopter werken. Luchtvarenden die achter in de helikopter werken, worden vaker aan de diverse fysiek belastende factoren blootgesteld dan de vliegers, maar er zijn ook overeenkomsten tussen de beide groepen. Zowel de vliegers als de luchtvarenden die achter in de helikopter werken, geven aan vaak hoofdbewegingen tijdens hun werk te moeten maken. Tevens dragen zij beiden een helm met daaraan additionele uitrusting gekoppeld, zoals nachtkijkers bij nachtvluchten. Op zoek naar mogelijke preventieve maatregelen voor vliegerrelateerde nekpijn, is dan ook gekozen om naar mogelijkheden te kijken die zowel voor vliegers als luchtvarenden die achter in de helikopter werken effectief kunnen zijn.

In hoofdstuk 7 staat het onderzoek beschreven dat gebruik heeft gemaakt van de ervaringen van de vliegers en de luchtvarenden die achter in een helikopter werken om de factoren te identificeren die verband houden met het gebruik van hun vliegerhelm en de relatie tot hun ervaren nekbelasting. Uit de resultaten blijkt dat het type vlucht, het gewicht en de gewichtsverdeling van de helm en de aangekoppelde uitrusting, direct worden gerelateerd aan de ervaren nekbelasting tijdens het vliegen. Maar ook de stabiliteit van de helm, de pasvorm van de helm en het comfort van de helm zijn factoren die indirect te maken kunnen hebben met de ervaren nekbelasting. Zo blijkt een stabiele helm van belang voor een gunstigere nekbelasting, omdat bij een onstabiele helm de gewichtsverdeling van de helm continu verandert. Het blijkt in de praktijk
echter moeilijk om de helm zowel stabiel als comfortabel te maken. Op basis van de resultaten van hoofdstuk 7 is wel een procedure ontwikkeld om het passend maken van de vliegerhelm te verbeteren. Dit heeft een nieuw protocol opgeleverd voor het pas maken van de vliegerhelm waarbij gebruik wordt gemaakt van een ander binnenwerk.

**Kan het optimaliseren van de pasvorm van de vliegerhelm de nekbelasting en nekpijn tijdens de vlucht verminderen?**

In hoofdstuk 8 is onderzocht of het optimaliseren van de pasvorm van de vliegerhelm invloed heeft op de ervaren nekbelasting, nekpijn, stabiliteit, drukpunten, irritatie/afleiding en comfort van de helm tijdens het vliegen. In totaal deden 18 vliegers en luchtvarenden die achter in de helikopter werken mee aan dit onderzoek met herhaalde metingen. Daaruit blijkt dat een geoptimaliseerde pasvorm van de helm resulteert in een vermindering van de ervaren nekbelasting tijdens de vlucht, in een stabielere helm, in een vermindering van de drukpunten op het hoofd ten gevolge van de helm en in een comfortabelere pasvorm van de helm. Tijdens het onderzoek bleek dat de ervaren nekbelasting tijdens de vlucht sterk gecorreleerd is aan de ervaren nekpijn (hoe lager de ervaren nekbelasting, hoe lager de ervaren pijn) en dat de mate van comfort sterk gecorreleerd is aan de mate van irritatie/afleiding ten gevolge van de helm (hoe hoger het comfort gevoel, hoe minder geïrriteerd of afgeleid tijdens de vlucht door de helm).

**Conclusies en aanbevelingen**

De belangrijkste conclusies en aanbevelingen op basis van de resultaten van dit proefschrift zijn:

- Gezien de percentages militaire luchtvarenden die aangeven nekpijn te hebben en dit te relateren aan het vliegen, kan nekpijn in deze werkende populatie worden beschouwd als een werkgerelateerde klacht. Het wordt de Koninklijke Luchtmacht aanbevolen om maatregelen te nemen om nekpijn in deze populatie te voorkomen.
- Een verminderde mobiliteit van de nek speelt bij F-16 vliegers mogelijk een rol in het krijgen van nekpijn. Een functioneel trainingsprogramma waarbij onder andere aandacht wordt besteed aan het behouden van de mobiliteit kan mogelijk bijdragen aan het verminderen van het aantal vliegers met nekpijn.
- De kracht, mobiliteit en positiezin van de nek zoals gemeten in dit onderzoek lijken bij de helikoptervliegers en de luchtvarenden die achter in de helikopter werken geen rol te spelen bij het krijgen van nekkachten. Andere functionaliteiten van de nek die in dit onderzoek niet zijn bepaald, kunnen mogelijk een rol spelen, zoals het uithoudingsvermogen van de nekspieren. Vluchten van 6 tot 8 uur zijn immers geen uitzondering in de militaire luchtvaart. Het wordt aanbevolen om onderzoek te doen naar de hoofdhoudingen en bewegingen tijdens het vliegen en deze in kaart te brengen met betrekking tot frequentie, amplitude en duur. Hierbij dient rekening te worden gehouden met verschillende type vluchten waarin deze houdingen en bewegingen met name voor de luchtvarenden die achterin werken verschillend kunnen zijn. Op
basis van de resultaten kan vervolgens worden bepaald welke fysieke vaardigheden en eigenschappen van de nek het meest bepalend lijken voor het uitvoeren van de werkzaamheden van vliegers en luchtvarenden die achter in de helikopter werken. Op basis hiervan kunnen functionele trainingsprogramma’s worden ontwikkeld en de effectiviteit van deze trainingsprogramma’s in het voorkomen van nekpijn dient vervolgens te worden onderzocht.

• Uit de evaluatie van de geoptimaliseerde pasvorm van de helm mag worden geconcludeerd dat dit resulteert in een vermindering van de ervaren nekbelasting tijdens de vlucht. Uit verder onderzoek zal moeten blijken of een geoptimaliseerde pasvorm van de helm ook op lange termijn leidt tot een vermindering van nekpijn. Het wordt aanbevolen om alle militaire luchtvarenden te voorzien van een geoptimaliseerde pasvorm van de helm. Het technische vliegeruitrusting personeel dat verantwoordelijk is voor het pas maken van de helm, zal hiervoor opgeleid moeten worden. Ook wordt aanbevolen om militaire luchtvarenden te informeren over het belang van een geoptimaliseerde pasvorm van de helm en welke factoren hierin bepalend zijn, zodat zij op tijd hun helm opnieuw kunnen laten aanpassen.

• Een geoptimaliseerde pasvorm van de helm is belangrijk. Niet alleen de ervaren nekbelasting wordt minder, maar luchtvarenden geven ook aan minder geïrriteerd of afgeleid te zijn tijdens de vlucht. Dit impliceert dat een geoptimaliseerde pasvorm positief kan bijdragen aan de vliegveiligheid. Het wordt de industrie aanbevolen om de pasvorm van de helm verder te optimaliseren door bijvoorbeeld het ontwikkelen van “custom made” vliegerhelmen.
Prevention of flight-related neck pain in military aircrew
Dankwoord
Dankwoord

Veilig geland bij het laatste en misschien wel meest gelezen hoofdstuk van dit proefschrift. De hoogste tijd om hen te bedanken die hebben bijgedragen aan het tot stand komen van dit proefschrift.

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Dankwoord


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Klaar! Het is tijd om het glas te heffen!
Publications


