Prevention of flight-related neck pain in military aircrew
General Introduction

Chapter 1
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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
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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<tr>
<td><strong>EXPOSURE</strong></td>
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<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>
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<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>
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<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>
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<tr>
<td><strong>DOSE</strong></td>
<td></td>
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<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>
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<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>
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<tr>
<td><strong>CAPACITY</strong></td>
<td></td>
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<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>ERGONOMIC 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>
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F-16 pilots

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].
General Introduction

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


