Prevention of flight-related neck pain in military aircrew

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Prevention of flight-related neck pain in military aircrew
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.
Optimal helmet use and adjustments with respect to neck load: The experience of military helicopter aircrew

**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
to bring their flight helmet to the interview so that they could provide clear answers with demonstrations. The interviewer verbally explained the purpose of the interview again prior to the interview and asked for permission to audiotape the interview. The number of participants when qualitative methods are used to analyze interviews is dependent on the determined sample diversity and the achievement of data-saturation. When the interviewer did not hear any new information during the interviews and a sample with a relevant diversity was interviewed, no further aircrew members were invited to participate. Data-saturation was later verified in the analyses.

**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 fit(ting); 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 fit(ting)” 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 lm 07 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 1.

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>Task-related factors</th>
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<tbody>
<tr>
<td>No obstruction of the visual field</td>
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<tr>
<td>Protection of face, eyes, head and hearing</td>
</tr>
<tr>
<td>Allows for good communication</td>
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<tr>
<td>Will not cause any head movement constraints</td>
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<table>
<thead>
<tr>
<th>User-related factors</th>
</tr>
</thead>
<tbody>
<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>
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<tr>
<td>Weigh as little as possible</td>
</tr>
<tr>
<td>One unit in all configurations / compatibility</td>
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<tr>
<td>Not causing any discomfort</td>
</tr>
<tr>
<td>Not being aware of wearing a helmet</td>
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<tr>
<td>User-friendly</td>
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**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”.

(p09)

“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”

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.
References


