Modern Air Combat Developments and Their Influence on Neck and Back Pain in F-16 Pilots

Stijn J. J. Thoolen; Marieke H. A. H. van den Oord

INTRODUCTION: Neck and back pain in fighter pilots remains a serious occupational problem. We hypothesized that recent advances such as the joint helmet mounted cueing system (JHMCS) in modern air combat might contribute to the development of spinal complaints in F-16 pilots.

METHODS: Surveyed were 59 F-16 pilots of the Royal Netherlands Air Force who were compared to 49 F-16 pilots who filled in a similar questionnaire in 2007. The prevalence of neck and back pain, work situations, and capacity of the pilot were analyzed.

RESULTS: The self-reported 1-yr prevalence of regular or continuous neck and lower back pain in 2014 were 22% and 31%, respectively, compared to both being 12% in 2007. Age, military flying experience, total number of flying hours, flying hours on the F-16, and total number of hours flown with night vision goggles (NVG) were significantly higher in 2014. In 2014, 95% flew with JHMCS, compared to 0% in 2007. Flying with JHMCS (88%), NVG (88%), type of flight (63%), and sitting posture (50%) were the most reported causes of flight-related neck pain. Sitting posture (89%), duration of flight (56%), and seat (44%) were among the reported causes of back pain.

DISCUSSION: The increasing trend of neck and lower back pain might be caused by multiple changes in both the work situation and capacity of the pilots since 2007. Future innovations will increase the load on the pilot's spine. To successfully address their spinal problems in the future, fighter pilots must be monitored continuously.

KEYWORDS: fighter pilots, spinal pain, joint helmet mounted cueing system, night vision goggles.

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Spinal pain in fighter pilots has been extensively discussed in the literature for more than two decades.[2,24] With more than half of the fighter pilots experiencing cervical or lumbar complaints,[8,12] often resulting in limited flight duty performance and even flight restrictions,[7,8,29] it remains a serious occupational problem. These complaints seem to be the result of the high-intensity work environment in which fighter pilots operate, with exposure to high acceleration forces, heavy equipment weight, and an unfavorable position of the pilot seated in the aircraft.[13,25,26] With the development of new technologies and ever lacking solutions to successfully address neck and back pain in fighter pilots, research in the etiology is of continuing importance. By determining what advancements in the fighter pilot environment play a role in the development of neck and back pain, preventive interventions can be proposed that suit the actual needs of the fighter pilot community.

Based on several conceptual models describing the relationship between work and musculoskeletal complaints,[3,28,30] factors that account for the etiology of neck and lower back pain in fighter pilots can basically be organized into two domains: capacity of the pilot and the work situation. Factors that are related to the work situation include procedures, equipment, work environment, and work conditions. Capacity-related factors include the physical, cognitive, and mental abilities of the pilot and determine the effect of the work situation on the pilot.[27] Previous studies have already identified factors in both domains that are associated with neck and back pain in fighter pilots.[8,13] We hypothesized that a change in these factors

From the Center for Man in Aviation, The Royal Netherlands Air Force, Soesterberg, The Netherlands.

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Address correspondence to: Marieke H. A. H. van den Oord, Center for Man in Aviation, The Royal Netherlands Air Force, Kampweg 3, 3769 DE Soesterberg, The Netherlands; mhah.vd.oord@mindef.nl.

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can lead to a change in the prevalence of musculoskeletal complaints in this population.

In 2007, we conducted a survey that was completed by F-16 pilots of the Royal Netherlands Air Force (RNLAF) and the Belgian Air Force (BAF) to determine the self-reported 1-yr prevalence of neck pain and compared characteristics of pilots with and without neck pain.[7] Since then, multiple changes in capacity- and work-related factors have occurred, including the implementation of new equipment and more flying at night, requiring the use of night vision goggles (NVG). One important development has been the implementation of the joint helmet mounted cueing system (JHMCS) at the RNLAF in 2008. This new technology allows for better targeting by pointing the head in the right direction, therefore encouraging head movement under high acceleration forces. In addition, it increases the mass of the pilot's helmet and subjects the cervical spine to an increased excentric load, possibly causing neck and back pain in F-16 pilots.[22]

In this study, we describe a population that has been subject to the latest developments in the fighter pilot community. Our aim was to determine whether there is a change in the self-reported 1-yr prevalence of neck and lower back pain between 2014 and 2007 and investigate possibly related developments in the work situation or capacity of the pilots. In addition, we sought to describe interventions to prevent neck and lower back pain, as proposed by the fighter pilots.

METHODS

Study Population and Procedures

An invitation to fill in an encrypted web-based survey was sent to all active F-16 pilots of the RNLAF. There were 59 pilots (61%) who voluntarily completed the survey between August and October 2014. Information about the aim of the survey and instructions were given in a preface. Confirmation was given when the survey was completed. Unfinished surveys were excluded from analysis. Ethical approval for the study was waived because the questionnaire was anonymous and contained no material subject to privacy constraints.

The results of a similar survey that was sent to all F-16 pilots of the RNLAF and the BAF in 2007 were described for comparison.[7] To minimize differences with our study population in 2014, the pilots of the BAF were excluded and only the F-16 pilots of the RNLAF that participated in 2007 ($N = 49$) were included for analysis. Data were collected on all correspondent questions.

Questionnaire

The questionnaire was based on the standardized 'Dutch Musculoskeletal Questionnaire'[17] and was extended with questions about flight-related factors. It consisted of 97 questions organized in four parts. The general part consisted of questions concerning individual factors, such as age, gender, body height, and bodyweight. The health-related part included questions about general health, physical and mental complaints, and physical training. The flight-related part included questions about flight experience, preventive strategies, and flight-related causes of neck and back pain. The neck and back pain-specific part included questions about the cause, characteristics, and progress of the pain. The questionnaire from 2007 did not include back pain-related questions, as it was focused on neck pain only. Selected items from the questionnaire were used to answer the specific research questions of the current study.

Statistical Analysis

The primary outcome measure was self-reported neck and lower back pain in the previous year. Pain was defined as any pain or discomfort. Possible answers for pain frequency were never, occasional, regular, or continuous. A figure was used to define different body regions, including the neck and lower back. To describe characteristics, progress, diagnosis, perceived causes, and treatment of neck and back pain, all pilots who had experienced regular or continuous pain were labeled as the Neck Pain Group (NPG) or Lower Back Pain Group (LBPG). Pilots who had experienced both neck pain and lower back pain were placed in both groups.

For comparison of factors related to the pilot's capacity and work situation between 2007 and 2014, the following variables in the analysis have been classified, based on our hypotheses as well as previous research.[8,10]

- Pilot's capacity: age (< 30 yr; 30–40 yr; ≥ 40 yr); body height; bodyweight; self-reported physical and mental fatigue at the end of the working day (yes/no); self-reported history of neck, shoulder, upper or lower back pain (yes/no).
- Work situation: flying with JHMCS (yes/no); years as a military pilot; total flying hours; flying hours on the F-16; total hours flown with NVG. Pilots were asked to fill in their flying hours according to their flight log. Flying hours were rounded to the nearest whole number. Pilots who never flew with NVG were included in analysis with zero hours.

Statistical analysis was performed with SPSS 22.0 (IBM Corp., Armonk, NY). Normally distributed variables are displayed as mean and standard deviation. Median and range are used to describe not normal distributions. Differences in prevalence of neck and/or back pain compared to pilots in 2007 were calculated using Pearson's Chi-squared test. To assess differences in capacity- and work-related factors, an independent samples *t*-test or a Mann-Whitney *U*-test was used as appropriate for numerical data. For nominal data, Pearson's Chi-squared test was used. For ordinal data, a Chi-squared test for trend was used. Differences were considered statistically significant if $P < 0.05$.

RESULTS

The self-reported 1-yr prevalence of regular or continuous neck pain (NPG) in 2014 was 22% (13/59), compared to 12% (6/49) in 2007 ($\chi^2(1) = 1.77$, $P = 0.183$). In 2014, another 37% (22/59) had occasional neck pain. In the NPG, 62% (8/13) attributed their neck pain to flying, compared to 33% (2/6) in 2007. In

2014, four of these pilots (50%) had mild pain and three (38%) had moderate or severe pain during flight. After flight, one pilot (13%) had mild pain and seven (88%) had moderate, severe, or very severe pain. The following factors were reported as a cause for their flight-related pain: flying with JHMCS (88%) or NVG (88%), type of flight (63%), sitting posture (50%), horse collar (38%), seat (38%), head posture (25%), head movement (25%), high G forces (25%), duration of flight (13%), and not enough flying hours (13%). A diagnosis was made by a physician in 31% (4/13) of the NPG, including cervical dislocation, scoliosis, and wrong body posture as a result of back complaints. There were 62% (8/13) who did not receive any therapy. Other pilots received manipulation, mobilization, massage therapy, physiotherapy, remedial therapy, or used medication. In 2007, none of the pilots were diagnosed by a physician or received any therapy for their complaints.

The self-reported 1-yr prevalence of regular or continuous lower back pain (LBPG) in 2014 was 31% (18/59), compared to 12% (6/49) in 2007 ($\chi^2(1) = 5.17$, $P = 0.023$). In 2014, another 34% (20/59) experienced lower back pain occasionally. In the LBPG, 50% (9/18) of the pilots attributed their complaints to flying. During flight, five pilots (56%) had mild pain and three (33%) had moderate or severe pain. After flight, all nine (100%) pilots had moderate, severe, or very severe pain. They reported the following factors as a cause for their complaints: sitting posture (89%), duration of flight (56%), seat (44%), flying with JHMCS (33%), type of flight (33%), NVG (22%), head posture (11%), high G forces (11%), horse collar (11%), and harness and G suit (11%). A diagnosis was made by a physician in 33% (6/18) of the LBPG, including a herniated disc in 2 pilots. Of these, 50% (9/18) did not receive any therapy. Other pilots received manipulation, mobilization, massage therapy, physiotherapy, remedial therapy, acupuncture, or used medication. Five pilots (28%) had been grounded because of their complaints.

Table I shows the comparison of factors related to the pilot's capacity between 2007 and 2014. Pilots in 2014 were found to be significantly older than in 2007 ($\chi^2(1) = 4.81$, $P = 0.028$). No significant differences were found between 2014 and 2007 regarding body height, weight, physical and mental fatigue at the end of the working day, and history of pain in related body areas. All pilots in 2014 and 2007 were men. Regarding capacity-related factors in 2014 that were not reported in 2007, general health and physical condition were reported as good in 92% (54/59) and 78% (46/59), respectively. In terms of exercising at least once per week, fitness training was most popular (85%) among pilots, followed by weight training (56%).

Table II shows the comparison of work-related factors between 2007 and 2014. Pilots had significantly more military flying experience in 2014, with a median number of 12 yr (range: 5–28), compared to 9 yr (range: 3–26) in 2007 ($U = 960.5$, $z = -2.88$, $P = 0.004$). Among other work-related factors, total number of flying hours ($U = 1085$, $z = -2.23$, $P = 0.026$), flying hours on the F-16 ($U = 826$, $z = -3.38$, $P = 0.001$), and total number of hours flown with NVG ($U = 616$, $z = -5.12$, $P = 0.000$) were significantly higher in 2014. In 2014, the median number of flying hours in the previous year (not reported in 2007) was 123 (range: 7–500), including a median of 10 h flown with NVG (range: 0–50). There were 56 pilots (95%) who reported that they fly with JHMCS.

In 2014, all pilots reported strategies to prevent neck pain. Reported strategies during flight were stretching (pre- and postflight) (61%), head posture strategies (head against rest, prepositioning of head, movement in one plane at a time, mindful about head posture) (86%), sitting posture strategies (back against seat, seat configuration, change of posture) (25%), and specific relaxation exercises (7%). Of the pilots, 12% did nothing during flight to prevent neck pain. A minority of the pilots reported preventive strategies apart from flight, including neck muscle strength training (7%) and physiotherapy (3%). Reported strategies to prevent neck pain in 2014 and 2007 are described in **Table III**. Strategies to prevent back pain during flight included stretching (34%), sitting posture strategies (64%), and specific relaxation exercises (2%). Of the pilots, 12% indicated that they use a cushion to support the back. There were 29% who did nothing during flight to prevent back pain. Reported strategies apart from flight were specific back exercises (32%), core stability training (29%), physiotherapy (2%), exercise walking (2%), and doing sports in general (5%).

Sixteen pilots who attributed their complaints to flying answered the question if they had suggestions for preventing flight-related neck and back pain. Eleven pilots suggested a change in capacity-related factors, including specific exercising and physiotherapy ($N = 8$), medical guidance or education

Table I. Factors Related to the Pilot's Capacity in 2014 and 2007.

	2014 ($N = 59$)	2007 ($N = 49$)	*P*-VALUE
Age			0.028*
<30 yr	29%	39%	
30–40 yr	46%	55%	
≥40 yr	25%	6%	
Body height, cm (SD)	182 (6)	183 (6)	0.844
Body weight, kg (SD)	81 (8)	83 (10)	0.312
Physical fatigue			0.834
Yes	68%	71%	
No	32%	29%	
Mental fatigue			0.439
Yes	86%	80%	
No	14%	20%	
History of pain			0.389
Yes	76%	67%	
No	24%	33%	

* Statistically significant ($P < 0.05$).

Table II. Factors Related to the Work Situation in 2014 and 2007.

	2014 ($N = 59$)	2007 ($N = 49$)	*P*-VALUE
Years military pilot	12 (5–28)	9 (3–26)	0.004*
Total flying hours	1794 (600 – 4600)	1300 (370 – 3900)	0.026*
F-16 flying hours	1418.5 (350 – 3238)	740 (40 – 2750)	0.001*
Total NVG† hours	123 (0 – 500)	30 (0 – 300)	0.000*
Flying with JHMCS‡	95%	0%	0.000*

Median values and ranges for flying hours and years as military pilot.
* Statistically significant ($P < 0.05$); †night vision goggles; ‡joint helmet mounted cueing system.

Table III. Reported Strategies to Prevent Neck Pain in 2014 and 2007.

PREVENTIVE STRATEGY	2014 ($N = 59$)	2007 ($N = 49$)
Strength training	7%	4%
Preflight stretching	61%	49%
Postflight stretching	3%	8%
Head against head rest	41%	16%
Prepositioning	83%	71%
Independent plane head movement	24%	18%
Nothing	12%	16%

($N = 6$), correct head posture and movement ($N = 1$), and doing sports in general ($N = 1$). Twelve pilots suggested a change in work-related factors, including more flying ($N = 3$), change of horse collar ($N = 5$), other measures to prevent the head from being pulled down ($N = 3$), and measures to support the back ($N = 5$). One pilot emphasized the need of acceptance of injuries in the pilot community. Three pilots had no suggestion, but indicated that their neck pain was an inevitable consequence of being a fighter pilot.

DISCUSSION

We hypothesized that recent advances in modern air combat might contribute to the development of spinal complaints in F-16 pilots. This study demonstrates an increasing trend in the self-reported 1-yr prevalence of neck and lower back pain in F-16 pilots of the RNLAF and shows multiple changes in both the work situation and capacity of the pilots between 2014 and 2007. Some researchers have emphasized the importance of the changing fighter pilot community in relation to spinal complaints,[20,29] but to our knowledge, this is the first study that objectively describes these developments over a period of multiple years.

Numerous studies regarding spinal complaints in fighter pilots have been conducted, using a wide variety of inclusion criteria and outcomes. Reported prevalence varies from about 50–83% for neck pain and from about 60–70% for back pain.[8,12,20] These results are consistent with the 1-yr prevalence of any neck and back pain, including occasional pain, of 59% and 64% found in our study. However, the huge discrepancy in the literature and lack of standardization make it impossible to detect any reliable signs of an increasing prevalence of spinal complaints as found in our study. By using the same definitions in 2014 and 2007, we were able to determine more accurately whether any change in prevalence has occurred over the years. We found two studies that are best comparable to our results. In 2000, Drew found a prevalence of any neck pain experienced at least once per month of 9% in German F-16 pilots.[8] More recently, Lange et al. demonstrated that 35% of Danish F-16 pilots experienced neck pain at least once per month during or immediately after flight in the preceding 12 mo.[20] One might suggest that these results support the possibility of an increasing prevalence of neck pain in F-16 pilots as well. The increase, however, could also be explained by differences in population, response rate and systematic bias, or underreporting.

The shift in capacity- and work-related factors may account for this increase in our population. We found that our population is significantly older than in 2007, which is in accordance with the increased military flying experience and increased total flying hours. Age is considered to be a risk factor for both neck and back pain,[18,21] although contrary results have been reported for fighter pilots.[23] Correspondingly, other studies did not find a relationship between flying hours and spinal pain.[8,29]

We speculate that the increase in neck and back pain in our population is more likely to be related to the higher number of hours flown with NVG and implementation of the JHMCS helmet since 2007. Our assumptions are supported by Lange et al., who have reported a sudden increase in neck pain incidents in experienced pilots after introduction of JHMCS.[20] Several studies have described spinal shrinkage, neck muscle strain and fatigue, and neck and back discomfort as a result of using weighted head-worn equipment.[9,14,25] The JHMCS helmet adds 2 kg to the load on the pilot neck, which can increase up to ninefold during high G maneuvers. The additional weight is mounted to the front of the helmet, shifting the helmet's center of mass and extending the moment arm. Mathys and Ferguson[22] simulated the effects of JHMCS on the pilot's neck in different postures at various accelerations. That study demonstrated that the increased weight and the forward-shifted center of mass lead to higher muscle activations and higher joint reaction loads over a wide range of head and neck movements compared to the HGU-55 helmet alone.[22] The JHMCS also adds 1.5 cm to the sitting height of the pilot. Some pilots might not fit into the cockpit without a forward-inclined head posture, increasing the load on the pilot's spine even more.[4]

The effect of NVG on the development of neck and back pain is more extensively discussed in the helicopter pilot community.[16] Greeves et al. reported that a higher number of hours flown with NVG is related to neck pain in helicopter pilots.[11] Like JHMCS, the increased helmet mass and a forward-shifted center of mass result in muscle strain.[25] Additionally, NVG highly reduce the field of view. To bring objects of interest into the line of sight and allow for proper targeting, new generation helmet enhancements like the JHMCS and NVG will demand more extensive head movement, increasing the chance of developing spinal complaints. In the past few years, fighter pilots of the RNLAF have become more operational at night. In combination with high accelerations, this may have induced spinal complaints. Consistent with the findings above, most F-16 pilots in our study reported factors that 'pull down the head', including JMHCS and NVG, as a cause for their flight-related pain, in combination with high G forces and an incorrect sitting posture.

Multiple pilots also reported the horse collar as a cause for their flight-related complaints and suggested changes to the horse collar for prevention. The horse collar functions as a safety vest after the pilot has ejected from the aircraft and was introduced to the RNLAF after 2007. According to the pilots, it exerts pressure on the neck and pushes the head in a forward direction during flight. This could further increases the moment arm of the center of mass of the already heavy equipment, leading to increased compressive force at the cervical spine.[22]

Adjusting equipment or aircraft design can be a lengthy and expensive procedure due to regulations and required testing in order to prevent flight-related spinal complaints. More feasible preventive interventions are found in factors related to the capacity and working method of the pilot, such as prepositioning, using the head rest or canopy as a support for the head and neck during high accelerations, and stretching exercises immediately before or after flight.[6] In our study, most pilots practice these in-flight techniques. Apart from flight, however, only a minority of the pilots specifically train their neck muscles. Several studies have investigated the effects of different training programs for the prevention of neck pain in fighter pilots.[1,5] A randomized controlled trial by Lange et al. concluded that 24 wk of targeted training proved effective in reducing neck pain.[19] Contrary to the number of pilots that pay attention to specific muscle exercising and physiotherapy, we found in our study that 50% of the pilots that suggested prevention interventions indicated that physical training would help. Training exercises, therefore, deserve a higher priority in the fighter pilot community. By education and better medical guidance, pilots might realize the beneficial effects of preventive exercising and understand the methods for fruitful training. Having training hours structurally built into the pilots' work schedules might help prioritize prevention apart from flight.

Other measures that might effectively reduce neck and back pain during flight have also been suggested. In our study, 31% of the pilots who had suggestions for prevention indicated that measures to support the back would help to reduce their flight-related complaints. Sovelius et al. found that lumbar support can relieve in-flight symptoms, reduce fatigue of the lower back muscles, and improve the sitting posture in some pilots.[26] Counterweights to prevent the head from being pulled down as seen in the helicopter pilot community are contraindicated for fighter pilots, as they are turned into a loading force leading to more muscle strain during extensive head movements.[15]

Continuously monitoring and changing selection criteria to screen out pilot candidates with a predisposition for developing injuries related to certain innovations might be necessary in the future as well. When JHMCS was introduced in the RNLAF, the pilot candidate's maximum sitting height was reduced by 1 cm to fit the F-16 cockpit.

Our data show that only one-third of the pilots with neck or back pain were seen by a physician and only half of the pilots received therapy. The problem of fighter pilots not seeking medical attention for their complaints is also described in the literature.[8,29] This confirms the statement of pilots that injuries need to be accepted among fighter pilots. We believe that this psychology is already shifting compared to 2007. This is further supported by our data, showing that none of the pilots with neck pain were seen by a physician or received any therapy at that time. Still, underreporting remains a considerable issue in the fighter pilot community. Misconceptions about the consequences of reporting complaints to flight surgeons and about their intentions to prevent spinal pain in the first place desperately need further attention.

This study was limited by the small number of pilots in the RNLAF and a successive independent sample design due to the anonymous approach of the survey, so a clear relationship between etiology factors and the increasing trend in spinal pain was difficult to validate. However, this study shows that the capacity and working environment of the F-16 pilot are evolving. Although fighter pilots might be less exposed to high accelerations in the future, the implementation of new equipment, such the JHMCS and NVGs, will increase the load on the pilot's neck. Conclusions drawn from older studies might not be completely applicable to the modern F-16 and recently introduced F-35 (Joint Strike Fighter) aircraft. We consider these advances as a potential hazard for the pilot that deserves particular attention. Hence, future research must be focused on the effects of future developments on the pilot's health.

In this study we address a well-known problem in the fighter pilot community. To keep up with the emerging technology in air combat, fighter pilots are in constant need of up-to-date information. Our data are recent and serve as a valuable contribution to confront this challenge. To successfully address their spinal problems, fighter pilots must be monitored continuously.

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Authors and affiliations: Stijn J. J. Thoolen, B.Sc., Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, The Netherlands, and Marieke H. A. H. van den Oord, M.Sc., Ph.D., Center for Man in Aviation, The Royal Netherlands Air Force, Soesterberg, The Netherlands.

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