Neck Pain in F-16 vs. Typhoon Fighter Pilots

Paola Verde; Pierandrea Trivelloni; Gregorio Angelino; Fabio Morgagni; Enrico Tomao

INTRODUCTION: In jet pilots, the neck is stressed by dynamic loading and there is growing concern about possible neck damage in pilots of new agile aircraft. Jet pilots often report neck pain after flight so intense that their operational capability may be affected. However, there is no clear evidence of structural damage related to the operational exposure.

METHODS: We compared 35 F-16 pilots with 35 age-matched Eurofighter Typhoon pilots. All subjects completed an anonymous questionnaire on their flight activity and neck pain.

RESULTS: The incidence of neck pain in the F-16 group was 48.6% compared with 5.7% of the Typhoon group, significantly higher. In F-16 pilots, there was a significant association between neck pain and age over 30 yr, total flight hours, and flight hours exceeding 600.

DISCUSSION: Our findings suggest that the risk of neck pain after flight is higher among F-16 pilots compared with Typhoon pilots. This could be due to several reasons, including the backward reclined seat of the F-16, which exposes the neck to the load in an unfavorable posture while moving the head during maneuvers at sustained high-G.

KEYWORDS: neck pain, cervical spine, jet pilots.

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An emerging problem with the implementation of modern agile jet aircraft is the overloading of pilots' neck muscles due to the high dynamic loads.[14,18,19] Some authors have reported a prevalence of neck pain in F-16 pilots between 50% and 83%.[1,3,12] Such prevalence is higher compared with the general population and has been accepted to be related to high G exposure.[14,18,19] There are no data for Eurofighter Typhoon pilots, although they consider that aircraft to be more comfortable than the F-16 for several possible reasons, including the cockpit geometry, the angle of the seat, and canard wings. Moreover, the F-16 has true fly-by-wire controls in which the movement of the stick is almost imperceptible and without force feedback, leading the pilots to obtain a very prompt response while maneuvering, but the maneuver may be more abrupt than anticipated.

The prevalence of spinal degeneration in the general population is associated with increasing age, beginning in the third decade of life, and may also be related to abnormal posture or repetitive movements in an occupational setting.[4,9] In jet pilots, the age-related degeneration of the cervical spine could be exacerbated by regular exposure to high $+G_z$. In fact, the high dynamic load[3,8,10] implies that the forces applied to the head act directly on the neck.[6]

The structural components of the neck are hard and soft tissues. The hard tissues include vertebrae and intervertebral disks that have a major role in sustaining the head while resisting compressive forces. This implies that the cervical spine has enough capability to bear a great load if it is applied along the spinal axis. The soft tissues include ligaments and muscles that stabilize and support the cervical spine by resisting tensile forces. These components also provide mobility. The center of gravity of the head falls forward to the ears, and thus anterior to the axis of the cervical spine, so the neck muscles are also actively involved in rest, preventing the head from flexing forward too much or too fast.[6]

A rapid decrease in the ability to support the cervical spine and the head under high G load has been demonstrated when the posture of the neck is abnormal, especially when the

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cervical tract is flexed, extended, or rotated with respect to the neutral position.[16] In the neutral posture, muscles are most effective in supporting the load, because the force moment that is expected to be supported is limited, and muscles have better mechanical advantage. Studies have shown that a load greater than +4 G_z is associated with increased risk of vertebral damage,[6,11] which occurs more frequently between C3–C7.

Many contributing factors have already been identified in the etiology of flight-related neck pain, including the number of flight hours, age, neck strength, and repeated exposure to high $+G_z$. The position of the head, its movements, the sitting posture, and vibrations are more likely to contribute to the genesis of neck pain.

A 30° backward reclined seat was implemented on the F-16 (ACES II) in order to increase the G tolerance through minimizing the blood displacement due to sustained high G. This results in a pilot's neck being flexed forward in order to look at the instrument panel that is located below the visual axis. Moreover, when doing "check six" with the F-16, a combined movement of extension with rotation and lateral bending of the cervical spine is required to look backward, starting with the neck unnaturally flexed forward due to the angle of the seat.

Helmet-mounted night vision devices and the modern instrumented helmets add more weight to the head and shift the center of gravity of the helmet,[6] increasing the risk of neck problems. These helmets were introduced to enhance the pilot's visual capability and maintain the target in view when it is not aligned with the vector of the aircraft. Given this, it is expected that the pilot will follow the target with substantial head movements, possibly exposing the neck to the effect of dynamic load in an unfavorable posture.[5]

In the current study, our aim was to assess the incidence of neck pain among fast jet pilots and to investigate whether any difference in symptoms exist between pilots flying the F-16 vs. the Typhoon. The null hypothesis was that there is no difference between these aircraft in terms of neck pain.

METHODS

Subjects

A group of 35 F-16 pilots was compared with a group of 35 Typhoon pilots. All pilots belonged to two fighter wings. Subjects of both groups were healthy, age matched men. None had neck abnormality of clinical relevance and all performed physical activity on a regular basis. Pilots of the F-16s wore the HGU-55 lightweight helmet, whose weight is about 1582 g, including the oxygen mask. Pilots of the Typhoons had the ACS helmet that is quite a bit heavier (1772 g included the oxygen mask). No night vision goggles or other special devices were mounted on the helmets in this study. With regard to the study design, the protocol met the criteria of the Declaration of Helsinki and was approved in advance by the Institutional Ethical Board (Aerospace Medicine Department protocol number 2012/09/24).

Questionnaire

An anonymous questionnaire was prepared by the Authors (**Fig. 1**). The questionnaire included one question on neck pain and a number of questions on age, total flying hours, and flight hours on F-16 and/or Typhoon aircraft. The questionnaire was delivered in Italian.

Procedure

A study briefing was given by one of the authors to all pilots, after which the questionnaire was delivered. Neck pain was defined as at least two episodes of neck pain after flight in the last 2 months.

Statistical Analysis

Data were analyzed with 2×2 contingency table and ANOVA as appropriate. The level of significance was set as usual at $P < 0.05$.

RESULTS

All pilots completed the questionnaire. The F-16 pilots were 32.54 ± 4.71 yr old and the Typhoon pilots were 33.37 ± 3.84 yr old, without significant difference. F-16 pilots had 1487.54 ± 897.29 total flight hours, while Typhoon pilots had 1768 ± 746.32 total flight hours, also not statistically different. Nine Typhoon pilots had previous flight experience with the F-16, while none of F-16 pilots flew the Typhoon.

We found that 17 of the F-16 pilots (48.6%) and 2 of the Typhoon pilots (5.7%) claimed to have suffered from at least two episodes of neck pain in the last 2 mo (Yates = 14.159, Relative Risk = 8.5, CI 95% from 2.2 to 52.17, $P < 0.001$). Both the Typhoon pilots that reported neck pain were formerly F-16 pilots.

Pilots of the F-16 group flew a mean of 562.83 ± 292.33 h on that type of aircraft, while pilots of the Typhoon flew 215.83 ± 187.15 h, which was significantly different [ANOVA $F(1, 68) = 35.0$, CI95% 82.97, $P < 0.001$]. Since the F-16 pilots flew twice the flight hours as the Typhoon pilots on the present aircraft, and in order to avoid the interference resulting from this difference, we selected a subgroup of subjects from each group with the same age, an equal number of total flight hours, and flight hours, respectively, on the F-16 and Typhoon. We collected two subgroups of 16 pilots each, without significant differences in terms of the above-mentioned variables. In these subgroups, neck pain occurred with an incidence of 10 cases (62.5%) among the F-16 pilots compared with only 2 (12.5%) within the Typhoon pilots (Yates = 6.533, Relative Risk = 5.0, CI 95% from 1.324 to 30.932, $P < 0.01$).

In the F-16 group, we found an association between neck pain and total flight hours (Yates 5.19, Relative Risk 3.11, CI 95% from 1.123 to 12.139, $P < 0.05$). We also found an association between neck pain and age over 30 yr (Yates = 5.19, Relative Risk 3.11, CI 95% from 1.123 to 12.139, $P < 0.05$), and number of flight hours on the F-16 exceeding 600 (Yates = 4.825, Relative Risk 2.44, CI 95% from 1.087 to 4.992, $P < 0.05$).

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SURVEY ON NECK PAIN AMONG PILOTS

The present questionnaire is part of a survey intended to obtain information on the frequency of neck pain after flight among flight personnel.
Participation is voluntary and anonymous.

AGE	TOTAL FLIGHT TIME

AIRCRAFT FLOWN AT PRESENT ____________

AIRCRAFTS FLOWN IN THE PAST (TYPE) ____________________________________

FLIGHT HOURS ON THE PRESENT AIRCRAFT ____________

FLIGHT HOURS IN THE LAST YEAR ____________

FLIGHT HOURS IN LAST SIX MONTHS ____________

NUMBER OF EPISODES OF NECK PAIN AFTER FLIGHT IN THE LAST TWO MONTHS RESULTING IN LIMITATION OF DAILY ACTIVITIES ____________________________

Fig. 1. Questionnaire delivered to pilots, translated in English. The draft used for the study was in Italian.

The association between neck pain and less than 500 flight hours on the F-16 was not significant.

DISCUSSION

The major finding of our study was that the incidence of neck pain was significantly higher among the F-16 pilots than among the Typhoon pilots. Moreover, the incidence of neck pain in our F-16 pilots was 48.6%, in accord with other investigations.[1,14,19] Although we did not investigate in depth the reasons for our results, our opinion is that the reclined seat of the F-16 contributes to neck pain in the pilots. In fact, the F-16 is fitted with a 30° reclined seat, whereas the Typhoon is equipped with a more vertically (13°) oriented seat. Therefore, in the F-16, pilots need an additional 15° forward flexion of the neck with respect to the trunk in order to maintain the direction of the gaze toward the horizon. Moreover, pilots automatically bend their head during a side bank maneuver in order to keep their eyes aligned with the horizon (optokinetic reflex).[7,15] This exposes the neck to a combination of flexion and bend in a less favorable posture.

Neck movement is extremely complex due to bone segment anatomy, the number of involved joints, and the spatial orientation of muscles. Rotation beyond 30° is critical because the neck rotator muscles have less isometric force generating capacity compared with the other groups of muscles.[9,16] Rotation, combined with flexion, leads to changes in the amplitude of neuroforamina: narrowing ipsilaterally and widening controlaterally. Nerve compression may result from a combination of extreme extension and rotation. Lateral bending combined with rotation and axial compression can result in a sprain of the intervertebral disk. Extreme extension is also critical because any load applied along the longitudinal axis of the body increases the extension of the neck, resulting in an excess load on the C7–T1 joints.[16] Moreover, the anterior neck muscles, whose role is counterbalancing the extreme extension, are the weakest muscular components. In extreme extension, the spinal canal and the neuroforamina between C5 and C7 are narrowed, so that nerve or medullar compression is possible.[9] Neck flexion is counterbalanced by the extensor muscles, which have the greatest isometric force generating capability. However, on the F-16, these muscles have to operate in an unfavorable posture, starting from a large elongation due to the neck flexion.[13] The "check six" maneuver is required to keep in view any target behind the tail, forcing the pilot to an extreme rotation of the neck. The rotator muscles have the lowest isometric force generating capability,[6] so it is difficult to maintain this posture for a long time. The combination between rotation, extension, and bend of the neck in the "check six" maneuver on the F-16 is probably the most challenging posture due to the abnormal distribution of the dynamic load between the components of the neck.[14,19]

The two aircrafts also have different cockpit geometries. On the F-16, the stick is on the right, throttle is on the left, and the control system is fly-by-wire. This means that the stick does not really move and pilots, especially those less experienced, grab the stick when pulling Gs. For this reason, pilots often report shoulder and arm pain in addition to neck pain.

We also found that in the F-16 group neck pain was associated with age. This could be explained by the progressive development of arthrosis, as it is known in the general population. However, the regular exposure to high $+G_z$ may increase the progression of symptoms. According to a previous study, in addition to flight-related issues, other physical and psychosocial factors play a role,[8] including any physical activity other than flight. For this reason, when dealing with a pilot with neck pain a number of conditions other than flight should be taken in consideration.

Total flight activity and more than 600 flight hours on an F-16 were associated with neck pain in our study, while less than 500 flight hours was not significant. The 17 cases in our study were distributed at the extremes of the relationship of cases vs. flight hours. This means that almost all pilots with neck pain had either very few flight hours or more than 700 h. Unfortunately, this reflected the distribution of pilots as well. For this reason, and because of the small number of cases, the association between neck pain and flight hours was statistically significant only when investigated in the 2×2 contingency table for 600 flight hours or more. Our opinion is that young pilots are at risk due to lack of physical training, while older pilots are also at risk due to a dose-response like effect. However, establishing a limit of exposure on the basis of appropriate studies would be helpful as a prevention strategy.

In our study, F-16 pilots wore the HGU-55 lightweight helmet, whose weight is about 1582 g, lighter than the helmet worn by Typhoon pilots (1772 g). Night vision goggles were not implemented at the time of the study. We did not measure the load with the helmet, but the helmet's weight under high Gs is easily computable: the heavier helmet in our study will weight 16 kg at +9 G_z. This weight is added to that of the head, which is about 4.5 kg (about 40 kg at +9 G_z), resulting in a force of about 550 N resting on the neck during the flight maneuvers, ten-fold greater than the value at 1 G. The use of helmet-mounted night vision goggles, or the adoption of the new instrumented helmets, would add even more weight over the neck.

A number of protocols and procedures have been proposed to minimize the impact of flight-related neck injury. An MRI scan in the pre-employment assessment would be helpful in identifying unfit subjects with abnormalities in any of the neck components. However, this would not necessarily protect individuals without pre-existing abnormalities from receiving damage due to the flight exposure. Moreover, special consideration regarding the cost-effectiveness of MRI as a screening procedure for military pilot candidates should be studied.

Physical training programs have been proposed in order to enhance the strength of the neck muscles.[1,2,18] To date, this seems to be a valid cost-effective strategy in minimizing neck pain, although further investigations are required to consider the effects of future helmets. Preflight warm-up techniques have been proposed in combination with the exercise program. Stretching and isometric exercises in warm ambient temperatures may be effective in reducing the risk of injury. In fact, there is evidence that warmed muscles contract quicker and harder than cold muscles, and low ambient temperature increases the risk of in-flight neck injuries.[17] Although a wide consensus exists between experts on the effective role of physical training, there is no validated protocol. Moreover, because of individual variability of neck strength and dimensions, an appropriate training program should be customized for each individual.[2]

The major limit of this study is that we used a questionnaire to assess neck pain. The study was made by grouping together all pilots of each unit only for the time strictly necessary to deliver the briefing and the questionnaire. Any diagnostic procedure, such as spine X-ray and physical examination, would have required extra time. Moreover, only actual disturbances would have been recorded, which were very few considering the limited number of subjects. However, we administered the questionnaire anonymously in order to encourage the subjects to answer sincerely. Another limit is that we did not measure the dynamic load. Since it is easily computable from the weight of the helmets and we did not need an accurate value for the analysis, the lack of data about the effective load is not a major limit. Finally, our sample of 70 pilots might be too small to provide statistically significant results. However, we conducted the study during the transition between the F-16, which is no longer in use in the Italian Air Force, and the Typhoon, so that we covered almost the entire population of F-16 and Typhoon pilots at that moment.

In conclusion, our data suggest an increased risk of neck pain in F-16 pilots compared with Typhoon pilots. This could be due to the less favorable posture of the body due to the reclined seat and cockpit geometry on the F-16. To be definitive however, the results of this study should be taken into account in the perspective of future implementation of heavier helmets. Further investigation would be helpful to validate a protective neck training protocol.

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