+Gz Exposure and Spinal Injury-Induced Flight Duty Limitations

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BACKGROUND: The present study aimed to find out if possible differences in early military flight career $+G_z$ exposure level could predict permanent flight duty limitations (FDL) due to spinal disorders during a pilot's career.

METHODS: The study population consisted of 23 pilots flying with G_z limitation (max limitation ranging from $+2\ G_z$ to $+5\ G_z$) due to spinal disorders and 50 experienced (+1000 flight hours) symptomless controls flying actively in operative missions in the Finnish Air Force. Data obtained for all subjects included the level of cumulative G_z exposure measured sortie by sortie with fatigue index (FI) recordings and flight hours during the first 5 yr of the pilot's career.

RESULTS: The mean ($\pm$ SD) accumulation of FI in the first 5 yr of flying high-performance aircraft was 8.0 ± 1.8 among the pilots in the FDL group and 7.7 ± 1.7 in the non-FDL group. There was no association between flight duty limitations and early career cumulative $+G_z$ exposure level measured with FI or flight hours.

DISCUSSION: According to the present findings, it seems that the amount of cumulative $+G_z$ exposure during the first 5 yr of a military pilot's career is not an individual risk factor for spinal disorders leading to flight duty limitation. Future studies conducted with FI recordings should be addressed to reveal the relationship between the actual level of $+G_z$ exposure and spinal disorders, with a longer follow-up period and larger sample sizes.

KEYWORDS: neck pain, low back pain, high-performance aircraft, G force.

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Exposure to high $+G_z$ force (acceleration resulting in a downward inertial force) in military aviation has been associated with an increased risk for spinal disorders.[6] Amount of $+G_z$ flight hours has been reported to be a significant determinant of acute in-flight neck pain,[2] and pilots flying fighter jets have reported higher prevalence of low back pain (LBP) than pilots flying nonhigh-performance aircraft.[5] Furthermore, it has been suggested that frequent exposure to over $+4\ G_z$ with a twisted neck position may cause premature cervical disc degeneration.[3]

In addition to $+G_z$ exposure, awkward neck posture during air combat maneuvering and poor cockpit ergonomics may also be an important underlying factor for cervical pain among fighter pilots.[10] Neck rotations and extensions during air combat may especially cause high stress on the cervical vertebrae.[1,6] Therefore, the common "check six" procedure (where the pilot is looking directly behind the aircraft, requiring maximal spinal rotation accompanied by extension) creates a significant risk for neck injuries.[8] Moreover, it has also been suggested that the upright position of the backrest of an ejection seat may stress the low back structures.[4]

Musculoskeletal disorders are ranked as the third most common reason after cardiovascular and neurological disorders for permanent medical flight disqualification among U.S. Air Force pilots and navigators.[7] Finnish Air Force (FINAF) pilots are rarely permanently disqualified due to musculoskeletal disorders. Instead the maximal G_z level that the pilot is allowed during any flight may be limited for a certain period of time. The G forces are regarded as a causative or aggravating factor, of which effects can be reduced by limiting the pilot's exposure to G

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forces. Limitations without airframe restrictions are commonly used during the rehabilitation of spinal problems in FINAF. If no improvement occurs in the musculoskeletal disorder, the limitation becomes permanent, thus influencing the pilot's career and loss of predicted working years. Spinal disc degeneration is the most common reason for aeromedical limitation in the FINAF. There are neither previous studies discussing the number of limitations due to spinal disorders nor the relationship between cumulative $+G_z$ exposure and spinal disorders. In previous studies, the typical indicators and measurements of pain are based on different questionnaires and pain indexes, while $+G_z$ exposure is characterized only by aircraft type and flight years or hours.[10]

The primary aim of the present study was to investigate if the cumulative $+G_z$ exposure levels during the first 5 yr of a military pilot's career could predict future permanent flight duty limitations due to spinal disorders. The first 5 yr of each pilot's career were chosen for analysis because according to Rintala et al.,[9] 93% of FINAF pilots reported flight-induced musculoskeletal pain after passing the agile jet training phase. Data in a group of pilots with permanent flight duty limitations were compared to respective data in an age-matched group of experienced fighter pilots without flight duty limitations. We hypothesized that pilots with flight duty limitations have had higher $+G_z$ exposure during the first 5 yr of their career compared to pilots flying without limitations. Another aim of the study was to introduce a new direct $+G_z$ measurement tool (Fatigue Index) instead of only presenting flight hours as a measurement of exposure.

METHODS

Subjects

All FINAF fighter pilots who had started their pilot training between the years 1995 and 2004, and had received permanent aeromedical limitations were chosen as the Flight Duty Limitation (FDL) group ($N = 23$). Pilots with any other medical problems than spinal disorders that resulted in flight duty limitation were excluded. Only pilots with more than 150 flight hours with high-performance aircraft (HPA) before limitation were selected to increase the probability that this was due to flight-induced spinal disorders. The range of the starting year at the Air Force Academy was chosen in order for subjects to have similar flight training and syllabus. Flight duty was limited to an average of 10 yr of flying HPA (ranging from 2 to 17 yr of flying). Out of 23 FDL subjects, 13 were flight limited between the sixth and ninth years of flying with HPA. The data for this retrospective case-control study were collected from the database of the Air Force Command Finland. All subjects were volunteers and provided written consent to participate in the present study. In addition, authorization was obtained from the Finnish Defense Forces' review board of research permits.

The make-up of the non-FDL group (pilots flying without limitations) consisted of five pilots with the highest number of flight hours and without permanent flight duty limitations from each Air Force Academy course that started between 1995 and 2004. The total amount of pilots in the non-FDL group was 50. All pilots were well-experienced F/A-18 fighter pilots in active operative duty. This selection method was chosen to ensure the same syllabus and flight training for subjects (FDL group) and controls (non-FDL group) at the early stage of their career. The exact flight hours are not reported because it is classified information, but each of the top five pilots had G_z-exposed flight experience between 1000–4000 flight hours without any spinal complaints leading to limitations in their medical history. Only male pilots were included in the study because of the limited number of female fighter pilots in the FINAF.

After limitations are set, pilots in the FINAF are allowed to fly only lighter missions with limited $+G_z$ level (maximum of 4 or 5 $+G_z$) with trainer jets or they are transferred to fly with other nonhigh-performance fixed-wing aircraft. The FDL group pilots in this study were flying either jet trainer (Hawk Mk 51 or Mk 66), transport (EADS CASA C-295M, Gates Learjet 35A, or Fokker F27), or liaison aircraft (Pilatus PC-NG 12). The pilots in the non-FDL group were actively flying F/A-18C Hornet fighters or Hawk Mk 51 jet trainers as flight instructor pilots, up to maximum of +7.5 G_z and +8 G_z, respectively.

Procedure

In the FINAF, flight duty limitations due to health reasons are used to guarantee flight safety and to reduce cumulative $+G_z$ load in order to promote recovery of a pilot's performance and health. In case of spinal disorders, G forces are regarded as a causative or aggravating factor, of which effects can be reduced by limiting the pilot's exposure to those G forces. During the first weeks of the G limitation, required spinal examinations (including MRI scanning) are performed, while physical therapy and personal training programs are started.

When flight duty is limited, the exact G limit is individually determined. The level of limitation varies normally from +2 G_z to +5 G_z, where pilots with +4 G_z and +5 G_z limits may, in some cases, continue their flying with primary trainers (propeller aircraft) or trainer jets. Most of the limited pilots are, however, transferred to fly liaison or transport aircraft, in particular all pilots with the +2 G_z or +3 G_z limit. The present study group was not further divided by the limitation level due to the small study population. All limitations from +2 G_z to +5 G_z were taken into account.

Data of flight hours and Fatigue Index (FI) collected from every flight was obtained from FINAF flight data recordings. FI was originally invented in 1970s by SAAB flight engineers in order to track aircraft (J35 Draken) structural fatigue due to in-flight acceleration forces. Since 1995, G_z loads of FINAF jet aircraft BAE Hawks and F/A-18C/D Hornets have been recorded into a database where aircrew can also be identified sortie by sortie. FI is determined by the number of times the levels of +0.25, +2.5, +3.5, +4.5, +5.5, +7.0, and +8.0 G_z are exceeded during the sorties or, respectively, are declined in the conditions of −0.5 and −1.5 G_z.

These values are recorded by the aircraft's accelerometer and stored by the flight data recorder. FI is calculated by these figures. There are different kinds of formulas for different models, wing modifications, part of fuselages, etc. The BAE Hawk mk51 formula (unpublished report: Hawk Mk 51A Fatigue Meter Formula, report BAE-BSS-RPHWK-FAT-0360, British Aerospace, 1996) for pilot tracking was chosen in the present study because pilots started their jet flight training in 1995 with this aircraft. The FI values from each sortie were then given a figure representing cumulative G_z exposure. This was calculated using the following equation:

$$FI = \left(5.17584*10^{-5}*m^2 - 0.4053*m + 771.2636\right)*10^{-7} \\ *(95.957*G_1 + 33.0343*G_2 + 0.3467*G_3 + 1.065*G_4 \\ + 19.177*G_5 + 69.8557*G_6 + 204.8637*G_7 \\ + 450.418*G_8 + 393.5057*G_9)$$

Where m = mass of aircraft and G_x = level of + G_z exceeded or $-G_z$ declined during the sortie; G_1 = @ −1.5 G_z, G_2 = @ −0.5 G_z, G_3 = @ 0.25 G_z, G_4 = @ 2.5 G_z, G_5 = @ 3.5 G_z, G_6 = @ 4.5 G_z, G_7 = @ 5.5 G_z, G_8 = @ 7.0 G_z, G_n = @ 8.0 G_z are exceeded during the sortie. Cumulative exposure for G_z is then determined per 1000 flight hours. The suggested maximum for follow-up on pilots' annual exposure is 13 FI/1000 flight hours. This figure comes from specific values for structural fatigue follow-up of a fighter aircraft (unpublished observation: Air Force Command Finland, order CK9720; July 7, 2014). However, this 13 FI is not a constant maximum that a pilot must not exceed. This system is introduced to increase pilots' and squadron leaders' awareness about who may be at risk due to intensive loading, and to be a tool for smart scheduling in order to manage occupational loading.

Statistical Analysis

Data were analyzed using SPSS Statistics for Windows version 21.0 software. Means with standard deviations are given as descriptive statistics. The Levene's test was used for testing the normality of variances. Student's *t*-test was used for comparison between the groups. The level of significance was set at $P \leq 0.05$.

RESULTS

Mean (± SD) age, body mass, and height of the study population is presented in **Table I**. There was no difference between demographic information among the present groups.

The mean (± SD) flight hours with $+G_z$ exposure of limited pilots was 1354 ± 451 h, ranging from 167 to 2280 h during an entire career. The respective $+G_z$-exposed flight hours of the non-FDL group ranged between 1000 and 4000 h. The average flight hours of the non-FDL group are classified. There was no statistically significant difference in actual flight hours flown during the first 5 yr of flying high performance aircraft between the FDL and non-FDL groups [$t(57) = 1.35$, $P = 0.183$].

Table I. Basic Characteristics (Mean ± SD) of the Non-FDL and FDL Groups.

DEPENDENT VARIABLES	FDL (*N* = 23)	NON-FDL (*N* = 50)	*P*-VALUE
Age (yr)	36.8 ± 2.2	36.1 ± 3.0	0.25
Height (cm)	178.4 ± 5.8	178.7 ± 5.5	0.84
Body mass (kg)	69.7 ± 5.4	71.7 ± 7.1	0.18
BMI	22.4 ± 1.6	21.9 ± 1.2	0.16
Seating height (cm)	92.8 ± 2.7	92.8 ± 3.0	0.95

The mean (± SD) accumulation of FI in the first 5 yr of flying high-performance aircraft was 8.0 ± 1.8 among the pilots in the FDL group and 7.7 ± 1.7 in the non-FDL group. When comparing the total accumulation of FI with the FDL and the non-FDL groups, no statistically significant difference between the groups was observed [$t(69) = 0.57$, $P = 0.574$]. When FI was divided per flight hours, there was no significant difference between the groups [$t(70) = 0.30$, $P = 0.411$]. This data (due to containing exact flight hours) is classified and not presented.

The most common reason for limitations was disorders due to disc degeneration with multiple prolapses in the cervical (C3–C7), thoracic (Th5–Th8), and lumbar (L3–S1) spine. A total of 15 pilots had been restricted due to disorders caused by disc degeneration and prolapses. The most common sites were cervical (11 pilots) or lumbar spine (8 pilots). Six pilots with cervical disc degeneration also had degenerative changes in either the cervical and thoracic or cervical and lumbar spine. Other reasons for limitations were spinal disorders due to ankylosing spondylitis (three pilots) and spondylolysis and/or spondylolisthesis in the lumbar spine (four pilots).

DISCUSSION

No statistically significant differences among the groups in flight hours or FI data were found. This suggests that accumulation of $+G_z$ exposure during the first 5 yr of a pilot's career may not be an independent risk factor for flight duty limitations due to spinal disorders. This result differs from a previous investigation,[10] which reports that fighter pilots exposed to high G forces may be at a greater risk for neck pain than pilots flying nonhigh-performance aircraft and who are, therefore, exposed only to low G forces. The symptom of pain itself is not leading to limitations in FINAF pilots because other signs and symptoms of illness/injury are needed (i.e., disc degeneration, etc.). Therefore, comparisons to previous studies have to be done with caution. Nevertheless, it has also been reported that there are no differences in the prevalence of LBP, cervical pain, or radiological disc degeneration when fighter pilots are compared to other (helicopter or transport) aviators or nonflying personnel.[10] This suggests that accumulation of $+G_z$ exposure is not associated with the prevalence of LBP and cervical pain. From this perspective, our results are in line with previous studies.[10]

For health promotion, the average amount of FI is restricted to 13 FI/1000 flight hours (per pilot) by FINAF headquarters. All of our subjects were flying below this limit. However, we are aware of individual flight missions (dogfights with a +8 G_z limit) where a pilot has been exposed to

25 FI/1000 flight hours during a single mission. Unfortunately, in the present data we had only yearly averages and, therefore, each individual mission was not analyzed.

We are not aware of studies reporting accumulation of G_z loading in military pilots. The +G_z exposure of FINAF pilots has generally been greater than in other fighter training programs due to FINAF doctrine emphasizing air-to-air flight training. Regardless, our data shows that +G_z exposure during 5 yr of fighter training with the Hawk jet trainer and F/A-18 Hornet does not differ between the study groups. With this result, we must reject our hypothesis that pilots in the FDL group would have greater G_z exposure in the early years of their career when compared to pilots of the non-FDL group. Several factors that potentially can influence the development of spinal disorders were not measured or controlled in the present study: accumulation of G_z loading over an entire career, individual control of head and trunk positions during G loading, and possible injuries or stress in leisure time activities. In particular, awkward neck posture may play a significant role in cervical pain due to flight mission maneuvers.[10]

The strength of the present study was the use of FI as a measure of exact individual cumulative G force exposure. As stated before, +G_z exposure is generally characterized in the literature only by aircraft type and flight years or hours.[10] Nonetheless, pilots flying with the same fighter aircraft may be exposed to totally different +G_z exposure due to different missions and flight syllabuses. There might be different +G_z exposures even within the same mission due to each pilot's personal skills, situational awareness, and maneuvers of the other (enemy) aircraft(s). With FI we get more information than that which is provided by flight hours and aircraft type.

Another strength of the present study is that the effects of spinal disorders on military pilots' work are measured using a concrete end-point: permanent flight duty limitations. In addition, the non-FDL group represents very experienced pilots with 1000 to 4000 flight hours without spinal disorders leading to permanent flight duty limitations.

A weakness of the FI method is that the system only records how many times given thresholds are exceeded. It does not take into account how long a pilot spends above the threshold. However, FI may be a useful tool to follow up on pilots' cumulative G_z exposure. It gives far more accurate data for cumulative G_z loads than flight hours as the acceleration forces vary greatly from sortie to sortie.

A weakness of this study is the small number of subjects in the FDL group. Nonetheless, the sample included the total number of limited pilots, which indicates that there is no bias in sampling.

Analyzing the data over a pilot's whole career may have had an influence on our results. There might be difference in FI (+G_z accumulation) among the FDL and non-FDL group pilots later in their careers. However, we wanted to be sure that the flight syllabus and missions were exactly same among the pilots in both groups. Therefore, we chose to analyze only the first 5 yr of flying in our analysis. Respectively, Rintala's[9] study showed that over 90% of pilots already have flight-related musculoskeletal symptoms during the first years of flying.

Because spinal disorders among military pilots are common[6] and may lead to early career limitations and, in a worst-case scenario in permanent flight disqualification,[7] it is important to reveal the causes of spinal disorders. Pilots transferred to desk jobs or nonhigh-performance aircraft with full fighter training are a huge loss both economically and operationally for any nation. Therefore, future studies should address the relationship between +G_z exposure and spinal disorders with larger sample sizes. It is recommended to measure the exact levels of +G_z exposure rather than measuring only flight hours. Furthermore, future studies should take into account the position of the neck during high G forces because an awkward neck posture may be a more important factor causing neck pain than the +G_z load itself. In addition, to investigate the effects of fighter pilots' career-long G_z exposure on developing degenerative changes in the spine, a more detailed loading analysis is needed. Studies must include flight intensity (ops tempo and peak loads) as well as recovery times. As G_z exposure seems not to be an independent risk factor for spinal degeneration, other personal characteristics such as anthropometry, strength, flexibility, range of motion, and their development over time should be studied in parallel with G_z exposure.

In conclusion, the results of this study do not support the original hypothesis that the early career +G_z exposure level (FI or flight hours) could predict future flight duty limitations. According to the present findings, it seems that the amount of +G_z exposure is not an independent risk factor for spinal disorders.

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