# Noise Exposure and Hearing Impairment in Air Force Pilots

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**OBJECTIVE:** The goal of this study was to estimate noise exposure and hearing impairments in Swedish military pilots. It also aimed to analyze possible relations between noise exposure and hearing impairments.

**METHODS:** The study group was an open cohort of 337 male pilots. They were longitudinally followed with pure tone audiograms every fifth year from the beginning of flight service until discharge. Outcome measures were prevalence of thresholds >20 dB HL and >40 dB HL at different ages, and incidence of impairments >20 dB HL, 30 dB HL, and 40 dB HL. Exposure variables were individual flight data and noise dose measurements. The ISO 1999 Database A was used for reference data.

**RESULTS:** At 50 yr of age, 41% of the pilots were exposed to an equivalent noise dose exceeding the EU action level of Leq 80 dB(A). We observed significant elevated prevalence values of thresholds >20 dB HL in all age classes compared to the ISO 1999 Database A. These elevations were most pronounced at ages 30 and 40 yr and at 4 and 6 kHz in the left ear. Significantly elevated prevalence values of thresholds >40 dB HL compared to the ISO 1999 Database A were observed at age 40 and 50 yr at 4 and 6 kHz. In a Cox analysis we observed elevated hazard ratios of deteriorating thresholds with longer flight time/year in fast jet pilots.

**DISCUSSION:** Military pilots had elevated prevalence values of hearing impairment. Of the subjects, 41% had been exposed to noise exceeding the EU risk limit. Increased flight time/year and flying fast jets were associated with elevated risk of hearing deterioration.

**KEYWORDS:** military, aircraft, dose, prevalence, incidence.

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Noise from aircraft has been a problem in the environment for passengers, but most of all for pilots and flight technicians, since the early days of aviation. Lindgren et al.[17] investigated noise and hearing impairment (HI) in Swedish commercial air traffic and found equivalent noise levels ($L_{eq}$) in the cockpit of different aircraft to be 75–81 dB(A) and estimated that an 8-h workday equivalent dose for the flight officers would be 72–78 dB(A). They found no indication of higher rates of HI in the study group compared to a reference population not exposed to noise. In contrast to this, Falcao et al.[3] observed an association between hearing loss affecting flying personnel and hours of flight in commercial air traffic in Brazil.

In military aircraft noise exposure is often higher than in civil air traffic. Rajguru[22] reviewed risk of noise induced hearing loss (NIHL) and prevention in military aircrews. He concluded that, though there has been advance in hearing protection devices (HPD), military surveys still show that even with the best hearing protection, NIHL is seen to occur.

High noise exposure in jet fighters is often associated with high speed and low-level flight tactics. The major sources of noise exposure during flight are external airflow around the aircraft and internal noise from the air conditioning system. This generated noise is often dominated by high-frequency sounds.[13] The noise exposure in helicopter cockpits, on the other hand, is generated by the turboshaft system connected to the rotors and

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is often dominated by sounds in the low-frequency area. It has been shown in numerous studies that high-frequency noise is a greater risk for hearing impairment compared to low-frequency noise of the same magnitude.[16,25]

The noise exposure at the entrance of the ear canal is a combination of the cockpit noise attenuated by the HPDs, and exposure from the electronic system for communication and alarms mounted in the HPDs or inside the helmet/headset. In military aircraft hearing protection is required to prevent NIHL and to keep signal communication intelligible during operations.[13] The noise exposure could not only be a threat to the hearing capacity of the pilots, but also to their performance, e.g., reaction time and the ability to communicate.[15,26] Negative effects from noise on flight safety and operational performance cannot be excluded.

Pääkkönen and Kuronen[21] observed the $L_{eq}$ of Finnish jet fighters during a typical flight mission of 96–100 dB(A) in the cockpit. The total equivalent noise dose from background and radio noise in the ear canal, under the helmet/headset, was 88–95 dB(A) during one sortie. The reported noise levels from the radio inside the helmet/headset were 4–10 dB higher compared to the background noise inside the helmet/headset.

In a French study on hearing in 20–40 yr old military pilots (fighters, helicopters, and transport aircraft), Raynal et al.[23] observed abnormal hearing levels at high frequencies, most prominent at 6 kHz. Helicopter pilots had a higher prevalence of HI at 3 kHz compared to fighter and transport pilots. In contrast to this, Orsello et al.[19] observed a higher rate of HI in fixed-wing compared to helicopter pilots. Owen[20] reported from the UK a threshold shift in excess of that expected from the ISO 1999 database A levels in helicopter aircrew with more than 10 yr of flying experience. In a study from the Turkish Air Force, Büyükcakir[1] reported that hearing loss at higher frequencies was significantly associated with flight hours and the noise from the jet planes were reported to be the main cause of the hearing loss. These studies are examples of investigations on noise exposure and hearing impairment in military pilots; however, no such study has been performed in military pilots in the Swedish Armed Forces (SAF) Air Force branch.

The aims of the present study were to:

1) Estimate the equivalent noise exposure in Swedish military pilots;
2) Calculate the prevalence of HI in Swedish military pilots using the ISO standard as a reference population; and
3) Analyze the relations between the noise exposure (flight time, type of aircraft, estimated equivalent noise dose) and the incidence of HI in Swedish military pilots.

## METHODS

### Material

The design was a retrospective register study, encompassing a longitudinal, open cohort. The cohort was open, meaning that participants were enrolled and resigned over time. The Swedish Air Force officers in the study were born between 1945 and 1980 and enrolled between 1963 and 2000. They were followed during their active service in the Air Force 1963 to 2010. The subjects included in the study were randomly selected to represent the entire group of officers during the study period. Data was collected from the medical files at the SAF Centre for Defense Medicine (active pilots) and in the Swedish Central Military Archive (personnel who have left the SAF for retirement or for other commitments). The selection was performed in such a way that the sample was representative of all pilots in the SAF 1963–2010. To be included in the study, they had to: 1) be an active or retired military pilot or aircrew member (in helicopters or transport aircraft) in the SAF; 2) have been in active flight service for more than 5 yr; and 3) have had more than 500 h of total flight time. The health records and the flight specifics of the pilots were followed every fifth year from the beginning of their flight service until they left the SAF. The women fulfilling the inclusion criteria were too few ($N = 5$) to allow a statistical analysis, so they were excluded from the study. In all 337 male Swedish Air Force officers were included in the cohort. The number of pilots was 316 and the number of other flying personnel was 21 (the entire group will be labeled as “pilots” hereafter). Most pilots flew fast jets (52.1%) and helicopters (31.6%), followed by trainers (10.8%) and transport aircraft (5.6%).

At 20 yr of age, 247 participants were tested with audiometry, at 30 yr 319, at 40 yr 229, at 50 yr 119, and at 60 yr 8 persons were still active. The eight persons still active at the age of 60 yr were excluded from the statistical analyses since they were too few. In accordance with the health regulations for pilots in the Swedish Air Force, many chronic diseases and lesions, with risk of incapacitation, are not consistent with flight duty. Examples of such conditions are diabetes mellitus, cardiovascular disease, neurological diseases, and afflictions of the middle and inner ear. All pilots are screened regarding such diseases on a regular basis. There is no information available regarding smoking habits or exposure to leisure time noise. The information available for each participant was: 1) personal data like year of birth, height, and weight; 2) audiograms, performed annually, or, if there were special reasons, every second year; and 3) recordings of flight time (in hours) and type(s) of aircraft used. The data for each individual were conveyed into an Excel database every fifth year, from enrolment to retirement from the Air Force. Since the study was retrospective, informed consent was not possible to achieve. Directly after collection of data, before the analysis, the individual identification for all included subjects was removed. Background data are presented in **Table I**.

### Procedure

Every pilot’s individual, accumulated flight time and the aircraft types used were registered every fifth year. A typical career of a Swedish Air Force pilot consists of two parts. During the first period the pilot has active flight duty with considerable time of flight training, often in fast jets. During this time period, often from the age of about 20 to about 40 yr of age, the pilots are

**Table I.** Background Data for the Study Group, 337 Male Military Pilots (and Aircrew).

| | YEAR OF BIRTH | AGE AT FIRST AUDIOGRAM | AGE AT LAST AUDIOGRAM | YEARS BETWEEN FIRST AND LAST AUDIOGRAM | TOTAL FLIGHT TIME, HOURS | TOTAL FLIGHT YEARS |
|---|---|---|---|---|---|---|
| Mean | 1958 | 21 | 43 | 22 | 2605 | 22 |
| Minimum | 1945 | 16 | 27 | 6 | 501 | 6 |
| Maximum | 1980 | 34 | 60 | 41 | 9893 | 41 |

exposed to intense noise. After that the officers are generally transferred from active flight duty to staff duty, or to flying helicopters or transport aircraft. Some retire from the SAF and go to civilian occupations.

Many different types of aircraft have been in service in the Swedish Air Force during the study period (1963–2010): fast jets, jet trainers, helicopters, and transport aircraft. The most common type of aircraft in the study group was fast jets followed by helicopters. A smaller proportion of the pilots flew transport aircraft or jet trainers most of the time. During the earlier part of the study, period piston engine propeller trainers and transport aircraft were also in service.

Noise levels were recorded in the cockpit and in the ear canal under the headset or helmet,[12] and measured during a typical flight mission. Such measurements were available for most of the airplane types used in the Swedish Air Force (classified reports). The measurements were carried out during the period 1995–2013. They are presented as $L_{eq}$ in dB(A) in the ear canal during an entire flight mission and they are based upon a 3-dB exchange rate. The subjects used for the noise measurements were pilots or, in the case of multiseat aircraft, also other crewmembers. They used individually fitted flight helmets or headsets with hearing protectors and communication integrated. The noise level from the communication system inside the helmets or headsets is included. In helicopters the $L_{eq}$ during a flight session was 97 dB(A) [range 95–98 dB(A)], in fast jets 89 dB(A) [range 82–95 dB(A)], in jet trainers 87 dB(A) [range 79–90 dB(A)], and in transport aircraft 80 dB(A) [range 68–83 dB(A)].

The noise data includes the time from when the pilots leave the flight squadron building for the flight mission until they return. The pilots could occasionally be exposed to high-risk noise levels from aircraft noise, close to or above 115 dB(A), at the runway or between the flight squadron building and the runway.

These noise exposure data for each type of aircraft have been used together with the logs of flight time and the logs of type of aircraft for each subject to calculate the accumulated equivalent noise dose for working time. This individual noise dose was calculated for every 5-yr period at the ages of 25, 30 yr, and so on. When not flying, the aircrew was exposed to normal office noise most of the working time. In the calculations this noise exposure was estimated to be 70 dB(A) ($L_{eq}$, 8 h) according to studies of Swedish office workers by Neitzel et al.[18] The pilots underwent training with small caliber firearms, with strict instructions to use adequate hearing protectors.

The accumulated equivalent noise doses normalized to 8 h working time a day ($L_{eq}$, 8 h) in dB(A), $L_{eq,T}$, at age 25, 30, 35 yr, and so on, were computed for each subject using the formula:

$$L_{eq,T} = 10\log\left[\frac{1}{T}\left(t_1 10^{0.1Lp1} + t_2 10^{0.1Lp2} + \ldots\ldots\ldots + t_n 10^{0.1Lpn}\right)\right]$$

where T is the total working time in hours (flight time and other time, 1800 h/yr, 8 h/d, 5 d/wk, 45 wk/yr); t is the time flying a logged type of aircraft or other time at work; Lp is the equivalent noise dose in dB(A) for a flight mission with the specific aircraft logged or, for nonflight activities, 70 dB(A); 1-*n* are the first to the *n*th periods.

As a part of the air safety program and the military hearing conservation program, all pilots and aircrew of the Swedish Air Force undergo comprehensive medical examinations on a regular basis. The medical examination includes pure tone audiometry performed annually or every second year (occasionally). Manual audiometers (Tegnér PTA 6 and PTA 8, CA Tegnér AB, Bromma, Sweden) were used up to 1990–1991. After that they were replaced by automated, computerized audiometers (Entomed SA 250, Entomed Med Tech AB, Malmö, Sweden). TDH-39 earphones (Telephonics, Farmingdale, NY) were used for both these audiometers. In 2001 these latter audiometers were replaced with another model of a computerized audiometer (Entomed GSI 66) equipped with Sennheiser HDA 200 earphones (Sennheiser Electronic Corp., Old Lyme, CT). The audiometers were calibrated according to internationally accepted methods[9–11] once a year. All hearing tests were performed in sound-insulated test rooms (T-cabins type 3240, CA Tegnér AB). Pure tone air conduction levels of the frequencies 0.5, 1, 2, 3, 4, and 6 kHz were determined in 5-dB steps employing the shortened ascending method using two of three responses in both the manual and the automated methods.[7] Only thresholds elevations exceeding 20 dB HL were registered in this study. Accordingly, thresholds better than 20 dB HL were not registered. Masking of the opposite ear was not performed. The nurses who performed the tests went through a standardized training program. This program included supervision and special training for the necessary changes when the automated audiometers were introduced.

**Statistical Analyses**

The group of military pilots studied was screened for otological diseases in two steps before enrolment. First, at conscription, mandatory to all Swedish men, only those with normal hearing or at most mild hearing loss were accepted as conscripts. Second, at enrolment to the Swedish Air Force, the cadets had to undergo a medical examination, including otological examination and audiometric tests to be accepted for the service.

As our study group can be considered as an otologically screened group, we have chosen the otologically screened and non-noise exposed standard ISO 1999 database A[8] as the most suitable comparison group.

Flight time/year, type of aircraft, and working time equivalent noise dose were used as exposure measures. Prevalence values of hearing thresholds ≥25 dB HL and ≥45 dB HL at single frequencies were used as outcome measures. The analysis of the data as prevalence values was chosen since only hearing thresholds exceeding 20 dB HL were registered. The observed prevalence values were tested against expected prevalence values from the standard ISO 1999 database A with a one-sample binomial test with the null hypothesis that the observed prevalence values were the same as in the standard.

Cox analyses were used to calculate hazard ratios (HR) and the outcome measures in this analyses were three incidences of hearing decline defined as one or more hearing threshold either ≥25, ≥35, or ≥45 dB HL at 3, 4, or 6 kHz in one or both ears, providing that all thresholds in the first hearing test were ≤20 dB HL at 3, 4, and 6 kHz in both ears. This was performed for ages 20–40 yr. We calculated the numbers of cases with incidence of hearing decline defined as above after 5, 10, 15, and 20 yr of exposure to aircraft noise.

The hearing thresholds of the pilots who left the Swedish Air Force at the age of 40 yr or earlier or at the age of 35 yr or earlier were tested using Chi-squared analyses against those who continued their service. This was made at the ages of 20 and 30 yr to control for a possible healthy workers effect. Microsoft Excel was used for the input of the data and to compute the noise doses. IBM SPSS Statistics 22 was used for the statistics. The Ethics Committee at Karolinska Institute, Stockholm, Sweden, approved this study (No. 2008/1685-31/2).

## RESULTS

In **Table II** accumulated total flight hours and equivalent noise doses normalized to 8 h/d are presented as mean and maximum values at the ages of 30, 40, 50, and 60 yr. The mean accumulated flight time at 50 yr of age was 3857 h. The mean $L_{eq}$, 8 h during working time, in the ear canal at 50 yr was 79.4 dB(A). At the age of 30 yr, 22.1% of the pilots exceeded the EU lower action level $L_{eq}$, 8-h working day, of 80 dB (A) and 4.2% exceeded the EU upper action level $L_{eq}$, 8-h working day, of Directive 2003/10/EC of the European Parliament of 85 dB(A).[2] At the age of 40 yr, 34.5% of the pilots exceeded 80 dB(A) and 6.6% exceeded 85 dB(A), and at age 50 yr, 41.2% and 11.8%, respectively, exceeded the EU action levels.

At the age of 40 yr, helicopter pilots had an average $L_{eq}$, 8 h, in the ear canal of 83 dB(A) [range 74–87 dB(A)], while fast jet, jet trainer, and transport aircraft pilots had a mean $L_{eq}$, 8 h, of 75–77 dB(A) (range 71–82). The total flight time as mean per pilot at age 40 yr was 1682 h in helicopters, 2045 h in fast jets, 1892 h in jet trainers, and 2448 h in transport aircraft.

The prevalence values of hearing impairment ≥25 and ≥45 dB HL in the right and the left ear at the frequencies of 0.5–6 kHz for the military pilots are presented in **Table III** and compared with data from the standard ISO 1999 database A. We observed significant elevated prevalence values of HI ≥ 25 dB HL compared to the ISO 1999 database A in all age classes at single frequencies in both ears. At the ages of 30 and 40 yr, the increased prevalence values were most pronounced at the frequencies of 3, 4, and 6 kHz. Significantly elevated prevalence values of HI ≥ 45 dB HL were observed at the age of 30 yr at 6 kHz, at age 40 at 4 and 6 kHz, and at age 50 yr at 3, 4, and 6 kHz in both ears. At 2 kHz we observed elevated prevalence values ≥25 dB HL compared to the ISO 1999 database A at age 30 yr in the left ear and at age 40 yr in both ears. At 0.5 and 1 kHz no elevated prevalence values were observed in any ear compared to the ISO standard.

HRs of incidence of hearing decline related to flight time/year from the Cox regression analyses are presented in **Table IV**. In the entire study group (all types of aircraft), we observed a significantly increased risk (HR) for threshold elevations of 25 dB HL or more of 19%/50-h increase of flight time/year (HR = 1.19/h) (Table IV). This dose-response tendency was observed in all individual types of aircraft, but was only significant in the fast jets. For fast jet pilots the risk (HR) increased with 38%/50-h increase of flight time per year. For the exposure measure quartiles of flight-time/year and median of flight-time/year we observed significant increasing risk (HR) of hearing decline in the total study group and in the fast jet group (Table IV). The most exposed group of fast jet pilots had a threefold increased risk of hearing decline (HR = 3.13) compared to the fast jet pilots with shortest exposure/year (Table IV).

The same tendencies were observed for the incidence of threshold elevations of ≥35 dB HL related to flight time/year, although these elevations were not significant (data not shown). For threshold elevations at ≥45 dB HL the number of cases was too small and the Cox analyses were not possible to perform

**Table II.** Accumulated Flight Hours, Equivalent Noise Doses in the Ear Canal, and Proportions of the Pilots Exceeding the Noise Doses 80 dB(A) and 85 dB(A).

| | | ACCUMULATED FLIGHT HOURS | | NOISE DOSE DURING WORKING TIME, $L_{EQ}$, dB(A) | | PROPORTION EXCEEDING EU NOISE DOSE, % | |
|---|---|---|---|---|---|---|---|
| AGE, YEARS | *N* | MEAN | MAX | MEAN | MAX | $L_{EQ} > 80$ dB(A) | $L_{EQ} > 85$ dB(A) |
| 20-30 | 319 | 966 | 2800 | 77.9 | 86.6 | 22.1 | 4.2 |
| 20-40 | 229 | 1913 | 5500 | 79.0 | 87.2 | 34.5 | 6.6 |
| 20-50 | 119 | 3857 | 7875 | 79.4 | 87.6 | 41.2 | 11.8 |
| 20-60 | 8 | 7028 | 9700 | 75.7 | 81.9 | 12.5 | 0 |

$L_{EQ}$: equivalent noise levels.

**Table III.** Prevalence Values of Hearing Thresholds ≥25 dB HL and ≥45 dB HL in the Right and the Left Ear and at Single Frequencies at Age 20, 30, 40, and 50 yr in % for Male Military Pilots and for ISO 1999 Database A, Males.

| | | MILITARY PILOTS, MALES, PREVALENCE VALUES, % | | | | | | | | | | | | ISO 1999 DATABASE A, MALES, PREVALENCE VALUES, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RIGHT EAR, FREQUENCIES, kHZ | | | | | | LEFT EAR, FREQUENCIES, kHZ | | | | | | RIGHT AND LEFT EAR, FREQUENCIES, kHZ | | | | | |
| AGE, YEARS, *N* | HEARING THRESHOLD, dB HL | 0.5 | 1 | 2 | 3 | 4 | 6 | 0.5 | 1 | 2 | 3 | 4 | 6 | 0.5 | 1 | 2 | 3 | 4 | 6 |
| 20 (335) | ≥25 | 0 | 0 | 1.2 | 1.3 | 4.5*** | 6.2*** | 0.4 | 0.4 | 2.4 | 2.7 | 4.5*** | 7.0*** | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 |
| | ≥45 | 0 | 0 | 0 | 0.8 | 1.6 | 2.7 | 0 | 0 | 0 | 0.4 | 1.2 | 2.6 | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 |
| 30 (319) | ≥25 | 0.6 | 0.9 | 1.2 | 3.5*** | 6.6*** | 14.0*** | 0.6 | 1.6 | 2.8*** | 4.7*** | 10.0*** | 20.7*** | ≤1 | ≤1 | ≤1 | ≤1 | 1 | 3 |
| | ≥45 | 0 | 0.3 | 0.3 | 0.6 | 1.2 | 3.7*** | 0 | 0 | 0 | 0.9 | 1.8 | 4.4*** | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 |
| 40 (229) | ≥25 | 0.5 | 1.8 | 2.7* | 6.3 | 18.3*** | 22.9** | 0.5 | 0.9 | 3.6*** | 12.6*** | 21.6*** | 29.7*** | ≤1 | ≤1 | 1 | 4 | 10 | 15 |
| | ≥45 | 0 | 0 | 0.5 | 1.9 | 5.1*** | 4.0*** | 0 | 0 | 0.5 | 2.4 | 6.9*** | 8.3*** | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 | ≤1 |
| 50 (119) | ≥25 | 1.7 | 1.7 | 6.8 | 19.7 | 33.3 | 40.4 | 0.9 | 0 | 9.4 | 24.8 | 41.9* | 51.8** | ≤1 | 1 | 7 | 20 | 34 | 40 |
| | ≥45 | 0 | 0 | 0.9 | 5.2*** | 14.6*** | 13.4*** | 0 | 0 | 1.8 | 6.9*** | 14.7*** | 21.4*** | ≤1 | ≤1 | ≤1 | ≤1 | 4 | 8 |

One-sample binomial tests have been performed with observed prevalence values against expected according to the ISO 1999 database A. The ISO database A values ≤1% have been used as 1% in the tests. *P*-values in the table are $^*P \leq 0.05$, $^{**}P \leq 0.01$, and $^{***}P = \leq 0.001$.

(data not shown). When the equivalent noise dose for working time ($L_{eq}$, 8 h) was used as an exposure measure in the Cox analyses, we did not observe any significant hazard ratios for the incidence of hearing decline ≥25 dB HL, ≥35 dB HL, and ≥45 dB HL (data not shown).

The total numbers of cases with incidence of hearing decline after 20 yr of aircraft noise exposure was at ≥25 dB HL, $N = 131$, at ≥35 dB HL, $N = 75$, and at ≥45 dB HL, $N = 34$. Most of these hearing declines occurred during the first 10 yr of exposure.

## DISCUSSION

A proportion of the military pilots were exposed to an estimated equivalent noise dose in the ear canal during working time ($L_{eq}$, 8 h) exceeding the lower and upper action levels proposed in the Directive of Noise from the European Union.[2] The upper action level [85 dB(A)] was violated in only a small proportion of the 30-yr-old pilots, but in 12% of pilots 50 yr old. The lower action level [80 dB(A)] was violated in considerably larger fractions, from 22 to 41% depending on age (Table II).

**Table IV.** Cox-Regression Analyses for Exposure Measure of Flying Time Per Year and Type of Aircraft.

| AVERAGE AMOUNT OF FLYING TIME PER SERVICE YEAR (HOURS)* | ALL TYPES | | HELICOPTER | | FAST JET | | TRAINER | | TRANSPORT | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *N* TOTAL CASES | HR (95% CI) | *N* TOTAL CASES | HR (95% CI) | *N* TOTAL CASES | HR (95% CI) | *N* TOTAL CASES | HR (95% CI) | *N* TOTAL CASES | HR (95% CI) |
| Continuous | 288 | 1.04 (1.01,1.07) | 91 | 1.02 (0.97,1.08) | 150 | 1.07 (1.02,1.11) | 31 | 1.00 (0.89,1.13) | 16 | 1.04 (0.97,1.11) |
| per 10 h | 132 | | 39 | | 73 | | 13 | | 6 | |
| Continuous | 288 | 1.19 (1.03,1.38) | 91 | 1.10 (0.84,1.45) | 150 | 1.38 (1.11,1.70) | 31 | 1.01 (0.56,1.81) | 16 | 1.22 (0.86,1.72) |
| per 50 h | 132 | | 39 | | 73 | | 13 | | 6 | |
| Categorical† | | | | | | | | | | Too few |
| <78 h | 71 | 1.0 | 33 | 1.0 | 27 | 1.0 | 10 | 1.0 | - | - |
| | 30 | | 14 | | 11 | | 5 | | | |
| 78–114 h | 71 | 0.88 (0.52,1.47) | 11 | 0.78 (0.26,2.36) | 48 | 1.15 (0.56,2.39) | 9 | 0.20 (0.02,1.70) | - | - |
| | 28 | | 4 | | 21 | | 1 | | | |
| 114–142 h | 71 | 1.40 0.87,2.28) | 15 | 1.10 (0.44,2.73) | 47 | 1.96 (0.96,3.99) | 8 | 0.95 (0.26,3.55) | - | - |
| | 37 | | 7 | | 26 | | 4 | | | |
| >142 h | 74 | 1.65 (1.01,2.69) | 32 | 1.22 (0.58,2.57) | 27 | 3.13 (1.41,6.91) | 4 | 1.32 (0.31,5.55) | - | - |
| | 36 | | 14 | | 15 | | 3 | | | |
| Dichotomous | | | | | | | | | | |
| >/< Median‡ | 288 | 1.61 (1.14,2.29) | 91 | 1.23 (0.65,2.31) | 150 | 1.96 (1.22,3.14) | 31 | 1.48 (0.48,4.56) | 16 | 1.14 (0.23,5.71) |
| | 132 | | 39 | | 73 | | 13 | | 6 | |

Outcome measure incidence of hearing thresholds exceeding 25 dB HL at 3, 4, or 6 kHz in one or both ears in the age interval of 20–40 yr. Hazard ratios (HR) and 95% confidence intervals (CI) are presented.

*Calculated by the total amount of hours between enrolment and the age 40 divided by years of service.

†Cut at the 25th, 50th, and 75th percentiles.

‡Cut at the median (50th percentile); 114 h for all types, 116 h for helicopter, 113 h for fast jet, 102 h for trainer, 172 h for transport.

The use of averages as exposure measures can mistakenly lead to the conclusion that the entire group is under the risk limits while a not negligible proportion of the group are above risk limits.

The noise in fast jets was high frequency dominated and emanated to a great extent from external air flow and internal air conditioning in the cockpit. Noise in helicopters and transport aircraft included more low frequency sounds.[13] The elevated risk for the pilots exceeding the lower and upper EU action levels was supported by our observation of significantly elevated prevalence values of hearing thresholds ≥20 dB HL and ≥40 dB HL among the pilots compared to the ISO 1999 database A standard. The elevated prevalence values were most pronounced at 30 and 40 yr of age at 4 and 6 kHz and are an indication of elevated prevalence of NIHL in the study group (Table III).

In the Cox analyses we observed significantly elevated HRs of hearing decline with increasing flight hours/year for the entire study group. The tendency was observed in all types of aircraft and was significant for the fast jet pilots (Table IV), but not for pilots of helicopter, training, or transport aircraft. This indicates that the high frequency dominated noise in the fast jets can result in an increased risk of NIHL compared to the more low frequency dominated noise from helicopters and transport airplanes. This observation is in agreement with an American study performed by Orsello et al.,[19] but in contrast to the findings reported by Raynal et al.[23] In the latter study the authors also described a notch in the audiogram at 6 kHz and poorer hearing in the left ear compared to the right. Gordon et al.[4] reported that total flying hours was a significant risk factor, but aircraft type was not. In a study in U.S. Air Force aviation related personnel, Greenwell et al.[5] observed that elapsed times since baseline audiogram were modestly associated with a decrease in hearing sensitivity, but aircraft type was not. The results in the studies cited are thus contradictory; in some studies jet pilots seem to have the greatest risk, and in another study helicopter crew have a higher risk. Our study supports the former concept, with a higher risk of HI for jet pilots.

When the noise dose ($L_{eq}$, 8 h) was used as an exposure measure, we found no elevated HR of hearing decline in the Cox analyses. An explanation to this could be that an elevation of noise exposure with 3 dB is equal to a doubled exposure time and this makes noise exposure far more sensitive to small measure errors compared to exposure time registration. There are different indications of what the best noise exposure measure is. In a study from 2011, Heyer et al.[6] demonstrated that duration of noise exposure divided into noise strata was a better predictor of NIHL compared to equivalent noise dose. This approach has been used in several other studies like Johnson et al.[14] and is also supported by the results in the present study.

The noise exposures of the military pilots differ from many types of continuous industrial noise, the basis for regulations. Short time periods of intense exposure are followed by long periods of low noise exposure at the air force base. The resulting equivalent noise dose can be the same, but the resulting risk of NIHL could differ.

In a study in the Finnish Air Force, Pääkönen and Kuronen[21] combined measured noise dose levels in the ear canal in different types of aircraft with group data on flight time. They concluded that the 8-h $L_{eq}$ was below risk limits and that the risk of HI in the pilots was not significant. According to our results from individual flight time data, this is also the case for a majority of the Swedish military pilots. However, a proportion of them (up to 41%) were exposed to hazardous noise levels above the current European action levels for preventing NIHL.[2]

Most of the hearing decline in our study was observed during the first 10 yr of exposure to aircraft noise. This observation is supported by an article reviewing occupational noise and hearing loss by Rösler.[24] The fastest progression in hearing loss was observed during the first 10–12 yr of noise exposure, most emphasized at 4 kHz.

A strength of this study is the long follow-up periods, up to 40 yr in individual cases, with the implication that a great proportion of the participants remained for many years in service as military pilots. The mean follow-up time was long, 22 yr, and with a mean flight time of 2605 h. The flight time records and aircraft types used were based on individual flight time logs for each participant, and this gives accurate data on the individual level. The measurements of the $L_{eq}$ during one flight mission were performed in a standardized manner for each type of aircraft. The study group was healthy, homogeneous, and otologically screened, which makes it comparable to the normal population in the ISO 1999 database A. Furthermore, the pilots were monitored with short and stated intervals according to their health, including hearing. Noise data from most aircraft types was available from the SAF and was part of the noise exposure estimations. Three different measures of noise exposure were used, flight time/year, type of aircraft used, and equivalent noise dose ($L_{eq}$, 8 h) in dB(A).

A limitation is that the screening level of 20 dB HL limits the possibilities of evaluating hearing thresholds. Since clinically measured hearing thresholds were not available, we were not able to use means, medians, and other statistical measures to describe the cross-sectional data. Instead we have used the prevalence values of hearing thresholds ≥25 dB HL and ≥45 dB HL.

A possible bias could be that pilots who were more sensitive to noise had left the Swedish Air Force earlier compared to those who continued their service. To control for this possible healthy worker effect, we tested the hearing thresholds at the age of 20 and 30 yr for those who left the service at the age of 35 or 40 yr or earlier against those who remained in service. We did not observe any difference in hearing thresholds between these groups and we conclude that we have no healthy worker effect in this study.

Pertinent findings of the present study are:

1. In spite of an average noise dose below EU risk limits in the entire cohort, equivalent working-time noise doses ($L_{eq}$, 8 h) above risk limits on an individual level were observed in up to 41% of the military pilots.
2. Elevated prevalence values of hearing thresholds ≥25 and ≥45 dB HL (compared to the ISO 1999 database A standard) were observed at the ages of 30, 40, and 50 yr. The most commonly affected frequencies were 4 and 6 kHz in both ears.

3. Increasing hazard ratio for the incidence of hearing threshold impairments ≥25 dB HL correlated to increasing noise exposure expressed as flight hours/year was observed in fast jet pilots but not in pilots in helicopter, training, or transport aircraft.
4. Most of the hearing impairments occurred during the first 10 yr of noise exposure.
5. Flight time divided into noise strata (type of aircraft) did predict NIHL. Noise dose ($L_{eq}$, 8 h) did not predict NIHL.

We recommend the current Hearing Conservation Program to be implemented rigorously, with special emphasis during the first 10 yr of service.

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