Extended High-Frequency Audiometry (9–20 kHz) in Civilian Pilots

Fengjie Ma; Shusheng Gong; Sha Liu; Mosheng Hu; Caihong Qin; Yin Bai

INTRODUCTION: The greater sensitivity of extended high-frequency audiometry (EHFA) than conventional audiometry (CA) for identifying early changes in hearing has been well documented in previous literature. However, no studies about EHFA were conducted on civilian pilots. The aim of this study was to investigate the usefulness of EHFA as an assay to evaluate civilian pilots' hearing status.

METHODS: An observational cross-sectional study was conducted on 134 civilian pilots (case group) and 101 subjects without noise exposure (control group). All of the subjects underwent CA (0.25–8 kHz) and EHFA (9–20 kHz). The potential of EHFA for identifying early changes in hearing was assessed.

RESULTS: The two audiometric tools both showed significantly higher hearing thresholds in the case group for most of the frequencies tested, but the differences were more obvious for EHFA. Compared with the control group, the average thresholds in the case group increased 3.15 dB at CA and 7.83 dB at EHFA for age 20–29. The number was 2.37 dB and 9.90 dB for age 30–39; 3.80 dB and 8.19 dB for age 40–49; and 10.84 dB and 16.86 dB for age 50–59. There were 74.6% of pilots who had hearing loss in at least in one ear and at one frequency in CA and 94.8% at EHFA. Significant differences in EHFA were observed also between pilots and their controls with normal hearing thresholds at CA.

CONCLUSIONS: EHFA is more sensitive than CA and could be useful in detecting subclinical changes of hearing in civilian pilots.

KEYWORDS: extended high-frequency audiometry, early detection, noise-induced hearing loss, civilian pilots.

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Although there may be some disputes, what we cannot ignore is that the sense of hearing is one of the most critical senses for civilian pilots. With the development of new technologies which include digital sound icons and 3D audio effects in civil aviation, more advanced listening will be required than for simple warning signals.[37] Hence, the importance of hearing will probably become even more evident. Hearing integrity is critical to the performance of pilots because perception errors can cause aviation accidents.[8] There is evidence that hearing loss can directly lead to decreased flight safety, maintenance failures, and even aircraft accidents.[34] Hearing loss has been ranked as one of the most important physiological sensory deficits affecting the safety performance of civilian pilots.[2]

Unfortunately, hearing loss is prevalent among the civilian pilot population.[17,28,31] Data from a longitudinal study that followed a sample of 3019 male civilian pilots over a 10-yr time course showed that the incidence rate of hearing deficit was 2.78% and the risk of hearing deficit increases progressively with pilot age.[28] Another study of 3130 male civilian pilots revealed that a total of 29.3% of pilots had suspected noise-induced hearing loss, which was bilateral in 12.8% and predominant in the left ear (23.7%); the number of pilots with suspected hearing loss increased as the noise exposure level increased.[9] There are many risk factors which may adversely impact the hearing function of pilots. Among them, noise in the challenging occupational environment holds a key role.[29] Considering the type of the aircraft, the phase of flight, the

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environment inside the cabin, and the outside weather conditions, the noise level can range from 80 dBA to 140 dBA in civilian operations.[5,14,37] This level may exceed the hazardous threshold, which is classified as an action level to start a hearing conservation program, a monitoring system to promote hearing protection according to the Occupational Safety and Health Administration (OSHA).[25] In addition to noise from occupational exposure, hearing loss is known to be related to advancing age.[7] A most recent study indicated that the prevalence of hearing loss was found in 33% of the male and almost 29% of the female participants ages 65 yr and older.[12]

Noise-induced hearing loss (NIHL) currently remains one of the most common occupational diseases and the second most frequently self-reported occupational injury in spite of implementation of hearing conservation programs.[30] Although NIHL cannot be reversed, it can be prevented. Early detection of hearing loss, which may halt the progression of the disorder, especially before involvement of speech frequencies, is of great importance. As to aviation safety, more benefit can be obtained from early detection of hearing loss in civilian pilots. However, the audiometric testing now performed periodically in civilian pilots' medical check is still restricted to conventional frequencies from 0.25–8 kHz. Frequencies ranging from 9–20 kHz, which have been proved to be more sensitive than conventional frequencies,[23,24,32] are not included in the routine test for civilian pilots.

Extended high-frequency audiometry (EHFA) is defined as threshold measurement above the frequency of 8000 Hz.[19] Elevated EHF thresholds have long been known to be linked with a history of noise exposure.[10,27,36] Although there are still some different opinions about the sensitivity of EFHA,[4,18,26] its potential usefulness for identifying individuals with increased vulnerability to noise insult is worth exploring.[19] The successful application of EFHA in detecting the early onset of drug-induced ototoxicity[3,13] is encouraging news for exploring its utility in NIHL.

EHFA has now been explored in individuals exposed to industry noises,[23,24,32] recreational noises,[19] music,[33] and even aviation noises in the military.[18] To the best of our knowledge, no studies to date evaluate the hearing function of civilian pilots using EHFA. The aim of this study was to investigate changes in extended high frequency thresholds in civilian pilots whose hearing statuses are closely related to aviation safety and evaluate the sensitivity of EHFA compared with conventional audiometry (CA).

METHODS

Subjects

This observational cross-sectional study was conducted on 150 civilian pilots holding Class I certificates (as the case group) and 109 subjects without noise exposure (as the control group). Audiometric data were obtained from May to October 2016. The data of pilots were collected at the Civil Aviation Medical Center of the Civil Aviation Administration of China (CAAC) during their periodic medical check. Subjects without noise exposure came from our colleagues working in the center. Written informed consent was provided by all subjects prior to their inclusion in the study. The Ethical Committee of our Institution gave approval to the study.

The CAAC establishes aerospace medical certification for the purposes of aircrew certification procedures. Medical certificates issued to Chinese civilian pilots are classified into four classes based on the strictness of the medical standard.[6] The medical standard applied to Class I medical certificates is

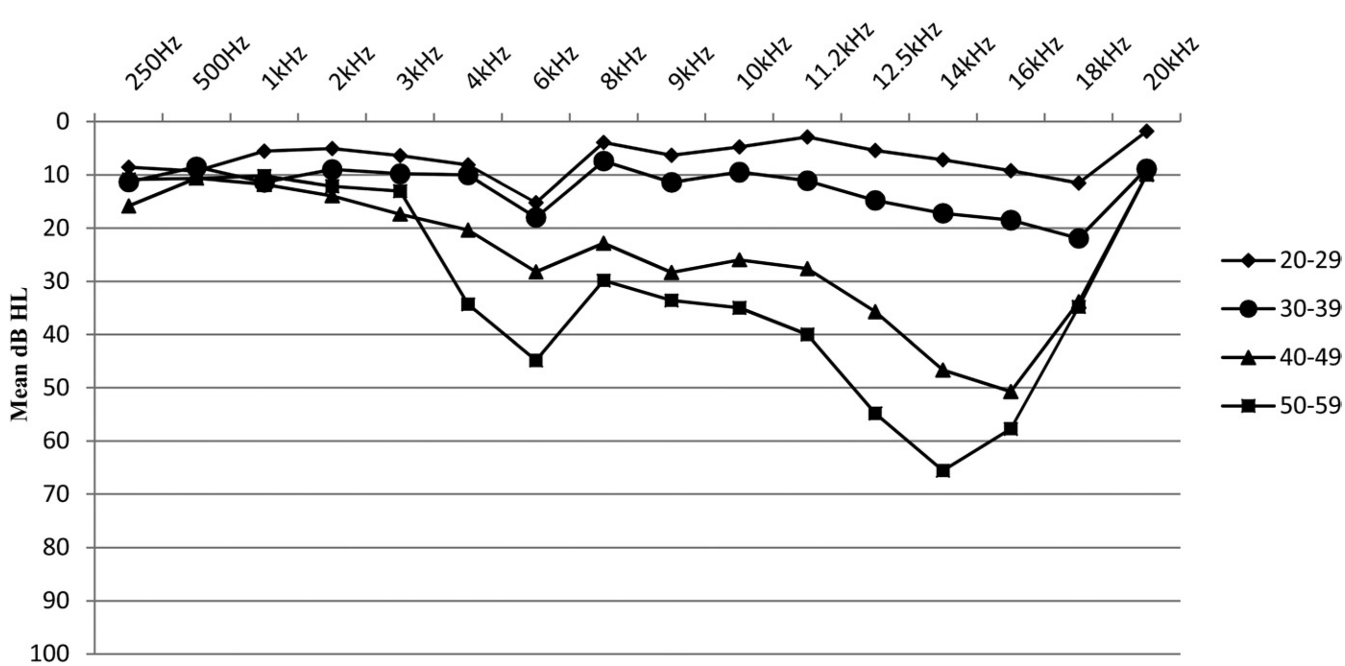

Fig. 1. Mean hearing thresholds of 101 subjects without noise exposure in various age groups.

Table I. Comparison of Mean Hearing Thresholds at Conventional Frequencies (0.25–8 kHz) and Multiple Frequencies (LFPTA, HFPTA) in dBHL Between the Case and Control Groups by Age Decade (Years).

	AGE	20–29		30–39		40–49		50–59	
kHz	**GROUPS**	**CASE**	**CONTROL**	**CASE**	**CONTROL**	**CASE**	**CONTROL**	**CASE**	**CONTROL**
0.25	Mean	11.59	8.60	14.4	11.34	13.6	15.83	16.30	10.89
	SD	6.23	4.46	6.28	6.14	6.31	6.89	8.58	3.35
	P	0.001		0.009		0.118 (n.s.)		0.005	
0.5	Mean	8.05	9.27	10.5	8.54	14.40	10.6	12.87	10.71
	SD	5.2	4.98	5.08	6.16	6.91	5.86	7.93	5.73
	P	0.118 (n.s.)		0.030		0.006		0.314 (n.s.)	
1	Mean	8.60	5.55	10.55	11.4	12.2	11.79	18.33	10.18
	SD	4.73	3.60	6.19	4.85	7.15	5.83	9.37	2.88
	P	0.000		0.227 (n.s.)		0.926 (n.s.)		0.000	
2	Mean	6.95	5.06	11.1	9.02	16.8	13.93	18.24	12.14
	SD	5.6	4.48	5.37	7.47	8.38	9.34	10.65	5.84
	P	0.031		0.021		0.179 (n.s.)		0.007	
3	Mean	6.40	6.40	9.15	9.8	16.4	17.38	28.43	13.04
	SD	5.52	6.00	8.99	6.54	13.17	13.85	19.42	5.33
	P	0.996 (n.s.)		0.176 (n.s.)		0.568 (n.s.)		0.000	
4	Mean	9.02	8.17	12.44	10	20.5	20.36	35.65	34.29
	SD	8.76	8.91	10.84	7.83	17.47	13.32	23.51	19.85
	P	0.583 (n.s.)		0.344 (n.s.)		0.644 (n.s.)		0.988 (n.s.)	
6	Mean	18.35	15.24	20.73	18	33.2	28.21	46.67	44.82
	SD	13.15	10.33	12.94	7.21	17.4	11.83	24.74	22.30
	P	0.127 (n.s.)		0.509 (n.s.)		0.284 (n.s.)		0.818 (n.s.)	
8	Mean	8.60	3.90	12.20	7.4	26	22.86	48.98	29.82
	SD	11.47	8.75	12.86	8.16	17.76	16.3	24.52	13.98
	P	0.001		0.066 (n.s.)		0.292 (n.s.)		0.000	
LFPTA	Mean	7.87	6.63	8.62	8.28	9.69	9.51	11.06	9.72
	SD	3.59	3.26	4.44	4.02	4.95	4.80	6.21	4.65
	P	0.029		0.807 (n.s.)		0.935 (n.s.)		0.113	
HFPTA	Mean	11.99	9.11	13.05	10.13	16.21	13.43	21.76	16.60
	SD	8.28	5.93	8.54	5.93	11.70	9.78	16.91	12.99
	P	0.006		0.007		0.045		0.003	

SD: standard deviation; *P*: *P*-value of the mean; n.s.: no significance.

the strictest. In order to have the certificate revalidated, pilots holding Class I medical certificates are required by the CAAC to have periodic medical checks every 1 or half year depending on age (1 yr for ages less than 40 and half a year for ages 40 and over). Pilots with valid Class I medical certificates are allowed to fly airline transport aircrafts, helicopters, and commercial aircrafts.[6] Civilian pilots were chosen because the noise exposure was severe, regular, constant, and without acute acoustic damage due to impulsive noise.[14]

Subjects were volunteers who filled out a "Hearing Status Investigation Questionnaire." Risky factors or complaints that may influence hearing include: family history of hearing loss, history of otitis media, otitis due to air pressure, previous middle ear disorders, use of potentially ototoxic drugs, frequent noisy leisure activities, heavy smoking, and drinking.

Equipment

CA and EHFA were conducted by trained otolaryngologists using a Madsen model Conera audiometer calibrated to JJG 388-2012 with high frequencies calibrated according to Annex C. Pure-tone air conduction thresholds were obtained using standard TDH-39 headphones for the frequency range of 0.25–8 kHz, and Sennheiser HDA200 circumaural phones (Wedemark, Germany) were used to test the 9–20 kHz range. All subjects were tested in a double-walled sound-proof chamber meeting ANSI 2004 specifications for audiometric test rooms.

Procedure

For all subjects enrolled in the study, those who had a positive history of risky factors or complaints as mentioned above were excluded. Audiometric tests were performed after at least 24 h had elapsed since last noise exposure to avoid any temporary hearing threshold shifts. Each subject was initially subjected to a general otolaryngological examination, including an otoscopic examination of both ears in order to ensure normal external ear anatomy and the absence of obstructions. Then subjects underwent tympanometric testing, followed by CA. To proceed to EHFA, subjects were required to be otoscopically and tympanometrically normal. Normal middle ear function was referred to as tympanometric structures with tympanogram peak pressure (TPP) values from −140 to +40 daPa,[22] static admittance (SA) values from 0.3 to 1.6 ml, and acoustic stapedius reflex can be elicited.

Hearing thresholds were established at conventional frequencies (0.25–8 kHz, calibrated in dBHL) and extended high frequencies (9–20 kHz, calibrated in dBHL) for both ears using the Hughson Westlake procedure with 5-dB steps. Provided that the subject failed to respond to the maximum intensity

Table II. Comparison of Mean Hearing Thresholds at Conventional Frequencies (9–20 kHz) and Multiple Frequencies (EHFPTA1, EHFPTA2) in dBHL Between the Case and Control Groups by Age Decade (Years).

	AGE	20–29		30–39		40–49		50–59	
kHz	GROUPS	CASE	CONTROL	CASE	CONTROL	CASE	CONTROL	CASE	CONTROL
9	Mean	11.40	6.34	14.51	11.4	35	28.33	53.61	33.57
	SD	13.11	10.97	14.42	7.49	21.31	16.99	25.35	15.74
	P	0.002		0.513 (n.s.)		0.237 (n.s.)		0.000	
10	Mean	8.90	4.76	15.37	9.5	35	25.95	56.94	35
	SD	12.47	11.27	15.17	7.46	22.61	18.49	25.13	18.21
	P	0.006		0.025		0.08 (n.s.)		0.000	
11.2	Mean	8.11	2.87	17.07	11.1	40.5	27.62	61.85	40
	SD	13.46	11.89	15.79	8.88	21.29	20.22	23.72	19.44
	P	0.002		0.042		0.003		0.000	
12.5	Mean	14.33	5.43	22.68	14.8	49.5	35.71	68.52	54.82
	SD	15.47	12.55	19.44	14.25	24.19	18.50	19.8	21.54
	P	0.000		0.009		0.007		0.006	
14	Mean	19.76	7.20	31.59	17.2	54.9	46.67	72.31	65.54
	SD	18.71	15.97	21.84	17.56	18.86	20.29	12.16	15.54
	P	0.000		0.000		0.035		0.023	
16	Mean	23.17	9.21	36.34	18.5	55.6	50.71	58.15	57.68
	SD	20.72	19.81	20.61	19.54	6.52	10.80	4.59	4.41
	P	0.000		0.000		0.014		0.49 (n.s.)	
18	Mean	20.30	11.52	29.33	21.9	34.8	33.81	34.81	34.8
	SD	14.08	15.33	8.08	14.84	0.99	3.09	0.95	20.95
	P	0.000		0.002		0.014		0.976 (n.s.)	
20	Mean	5.85	1.83	8.66	8.9	10	9.88	10	10
	SD	5.82	6.46	3.05	3.82	0	0.77	0	0
	P	0.000		0.185 (n.s.)		0.275 (n.s.)		1 (n.s.)	
EHFPTA1	Mean	9.47	4.65	11.75	6.93	17.61	11.85	25.64	15.22
	SD	12.24	10.61	12.81	9.72	18.53	1.93	25.40	17.30
	P	0.001		0.000		0.001		0.000	
EHFPTA2	Mean	19.09	7.28	21.43	10.90	28.89	18.98	36.43	24.57
	SD	16.38	14.78	17.08	15.76	21.43	20.99	24.85	24.43
	P	0.000		0.000		0.000		0.000	

SD: standard deviation; *P*: *P*-value of the mean; n.s.: no significance.
The degrees of freedom of the case and control groups for age 20–29 are both 40. For age 30–39, they are 40, 24; 24, 20 for age 40–49; and 26, 13 for age 50–59.

output of the high-frequency audiometer (which was 5 dBHL for 20 kHz, 30 dBHL for 18 kHz, 55 dBHL for 16 kHz, 75 dBHL for 14 kHz, 85 dBHL for 12.5, 90 dBHL for 11.2, and 10 and 100 dBHL for 9 kHz), the next higher level (following a 5-dB step) was recorded as the hearing threshold for the subject for the statistical analysis.[32] We defined hearing loss as thresholds higher than 20 dBHL[1] or no response at each frequency in CA and EHFA. Calibration of EHFA in dBHL was provided by the manufacturing company. If the difference between test and retest hearing thresholds for each frequency was no more than 5 dB, the response was considered reliable.

Statistical Analysis

The data was analyzed by SPSS version 19 using the Wilcoxin signed-rank test, *t*-test, and Chi-squared test. Normality of the distribution was assessed using the Kolmogorov-Smirnov test. If the data were normally distributed, two-tailed *t*-test was used. The Mann–Whitney nonparametric test was used if the normality assumption was violated. The prevalence of hearing loss was compared using the Chi-squared test. *P*-values of < 0.05 and < 0.01 were taken as the significant and highly significant levels, respectively.

To control the effect of age on hearing thresholds, all the subjects were divided by age decade into four groups (20–29, 30–39, 40–49, 50–59 yr). To reduce the effect of random test-retest variability and explore patterns of change, a comparison of the averages of multiple thresholds (LFPTA: 0.5, 1, and 2 kHz; HFPTA: 4, 6, and 8 kHz; EHFPTA1: 9, 10, 11.2 kHz; and EHFPTA2: 12.5, 14, and 16 kHz) was also conducted. Considering strong right-left correlations and small right-left differences, thresholds for right and left ears were averaged for all analyses.

To investigate the possible usefulness of EHFA as an early indicator of noise insult, the means of extended high frequency hearing thresholds of 32 civilian pilots with any value ≤ 20 dBHL at conventional frequencies (0.25–8 kHz) were compared to that of 34 subjects without noise exposure. The prevalence of hearing loss among active pilots between CA and EHFA was also compared for this purpose.

RESULTS

There were 134 civilian pilots (the case group) and 101 subjects without noise exposure (the control group) enrolled in this study according to our screening procedures. All subjects were men. The mean flight time of the pilots was 1381.1 h for 20–29 yr, 5868 h for 30–39 yr, 10,296 h for 40–49 yr, and 18,163 h for

50–59 yr. The mean age of the control group was 35.8 yr, whereas the mean age of the case group was 38.1 yr ($P < 0.05$). The rate of using otoprotectors (noise-cancelling headsets) to avoid noise insult for civilian pilots investigated in this study was 9.3%. The mean hearing thresholds of subjects without noise exposure can be seen from **Fig. 1**. The general trend clearly shows that hearing thresholds at all frequencies increased with increasing age and were more marked in 40–49 yr up to 16 kHz. Hearing thresholds were similar in all age groups up to 50 yr at conventional frequencies. Differences of hearing thresholds at 6 kHz in CA and 14 kHz and 16 kHz in EHFA were more marked of all the frequencies tested.

The SD was generally greater in the extended high frequencies (with the exception of 18 kHz and 20 kHz) than that in the conventional frequencies. This indicates greater intersubject variability in the extended high frequency range than that in the conventional frequencies. The thresholds difference between age groups at EHFA was greater than that at CA. This may be due to the higher vulnerability of extended high frequencies.

The means of hearing thresholds between the case and control groups were compared by age decade (years). As shown in **Table II**, for each age decade, civilian pilots had significantly higher mean hearing thresholds than subjects without noise exposure at most of the extended high frequencies tested. Particularly, the largest difference between hearing thresholds was found at 16 kHz for subjects ages 20–29 and 30–39, at 12.5 kHz for 40–49 yr, and at 10 kHz for 50–59 yr (**Fig. 2**). Relatively less marked differences can be seen for conventional frequencies (**Table I**, Fig. 2). Compared with the control group, the average thresholds in the case group increased 3.15 dB at CA and 7.83 dB at EHFA for ages 20–29, 2.37 dB at CA and 9.90 dB at EHFA for ages 30–39, 3.80 dB at CA and 8.19 dB at EHFA for ages 40–49, and 10.84 dB at CA and 16.86 dB at EHFA for ages 50–59.The findings were consolidated by the comparison of the means of four groups of multiple thresholds (LFPTA, HFPTA, EHFPTA1, EHFPTA2) between civilian pilots and subjects without noise exposure (Table I, Table II).

Fig. 3 compared hearing thresholds in the extended high frequencies of 32 pilots with any value in both ears ≤20 dBHL in the conventional range (0.25–8 kHz) and 34 controls, subdivided into two groups by age. There were 18 pilots and 27 controls for 20–29 yr, and 24 pilots and 7 controls for 30–39 yr. As can be seen from **Table III**, there were statistically significant differences in the extended high frequencies at 12.5, 14, 16, 18, and 20 kHz for ages 20–29 yr and at 14, 16, and 18 kHz for ages 30–39 yr. No pilots over 40 with hearing thresholds ≤20 dBHL in the conventional range were found in our study.

The prevalence of hearing loss at EHFA was significantly higher than the conventional frequencies among civilian pilots in each age group with the exception of ages 50–59 yr (**Table IV**). Totally, 74.6% of pilots had hearing loss in at least in one ear and at one frequency in CA. This measure was 94.8% in the extended high frequencies. And 6 kHz and 8 kHz in CA, and 18 kHz and 20 kHz in EHFA were frequencies with a very high occurrence of abnormal hearing threshold.

DISCUSSION

NIHL is a slowly bilateral, progressive sensorineural hearing loss at high frequencies resulting from prolonged exposure to noise. The increasing prevalence of NIHL is one of the main reasons for hearing loss in adults. NIHL not only affects the way people communicate, but also has a negative impact on people's mental health, thereby reducing quality of life. Hence, early detection of subtle changes in hearing thresholds is essential for

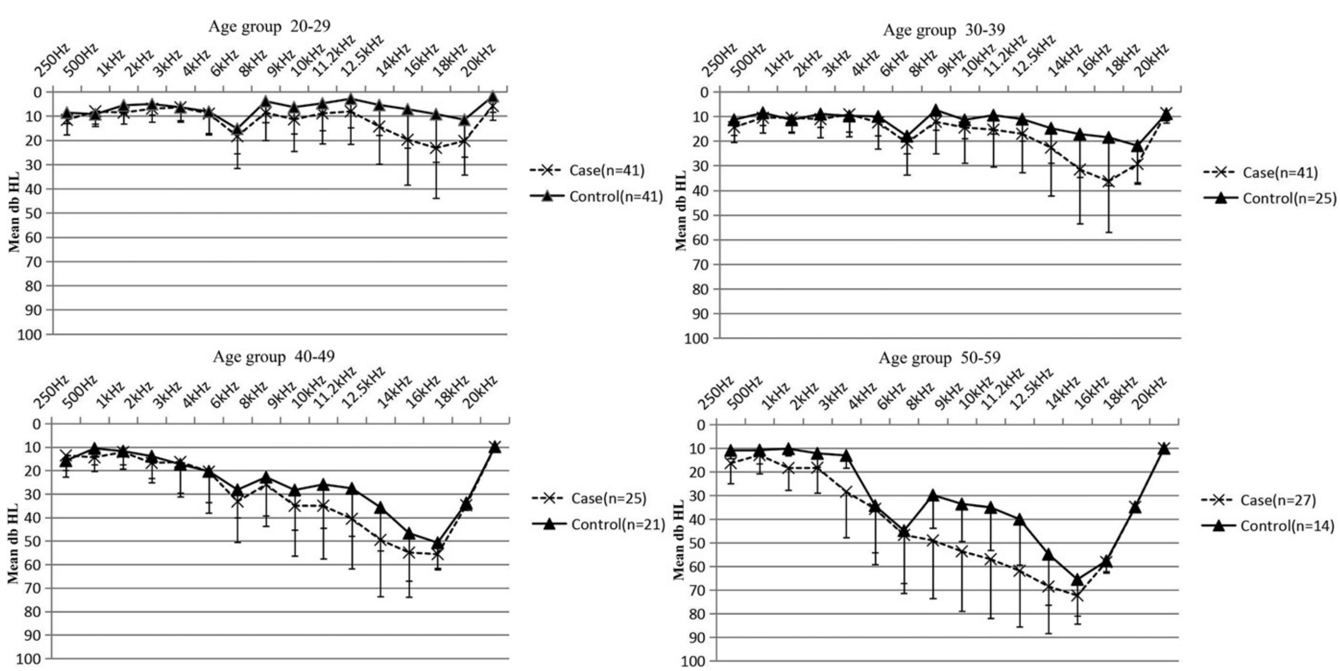

Fig. 2. Mean hearing thresholds of case vs. control groups by age decade. Error bars refer to standard deviation of the mean.

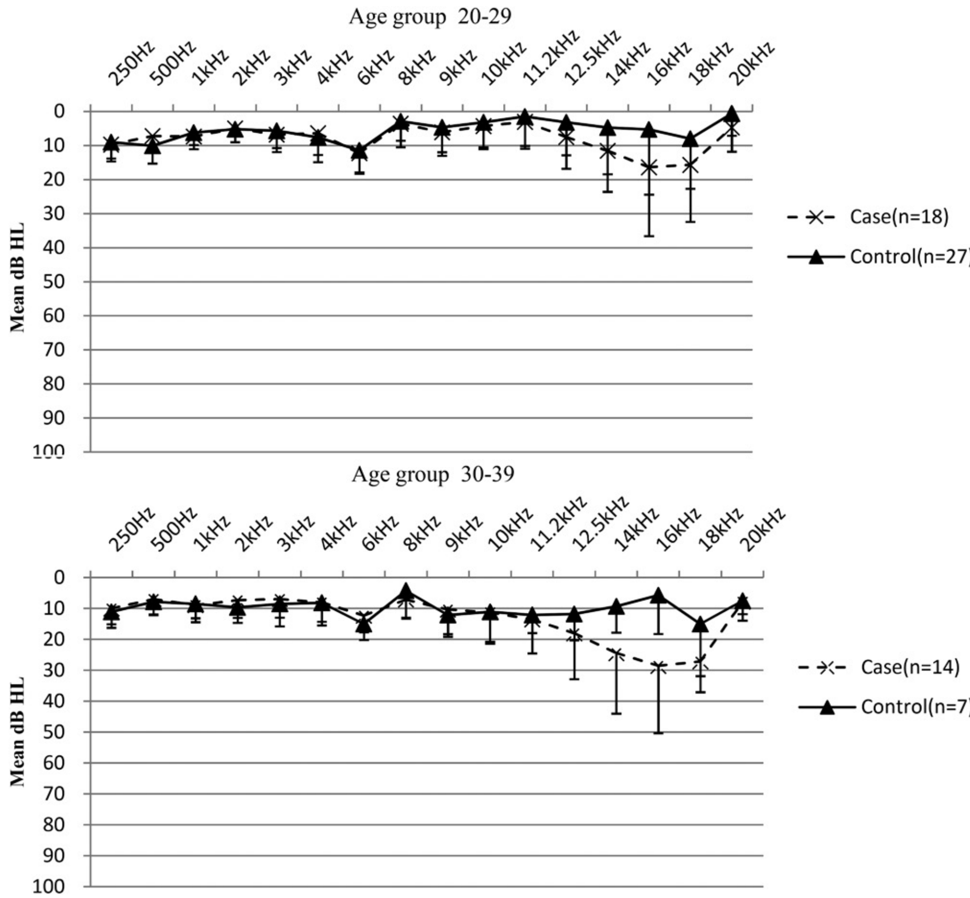

Fig. 3. Mean hearing thresholds of case vs. control groups with any value ≤20 dBHL in the conventional range. Error bars refer to standard of the mean.

the prevention of this irreversible disease. For pilots who have predominant roles in aviation safety, it is vital to find a sensitive audiometric test assessing their hearing ability. However, CA, which has poor sensitivity, is now the only tool to evaluate the hearing function of civilian pilots. Recently, EHFA, which is more sensitive, has been proposed as an effective method to detect hearing loss at an earlier time. With the use of newer audiometers, the inter- and intrasubject variations have been strongly reduced. And many studies have shown that the reproducibility of EHFA is comparable to that of CA.[32] In addition, EHFA is easy to conduct, requires the same instrument used for CA, and only a few minutes to be performed.

Our findings show that civilian pilots had a significantly higher mean hearing threshold than subjects without noise exposure at most of the extended high frequencies tested. Less marked differences were observed for conventional frequencies. When we evaluated the reliability of EHFA as an early indicator of NIHL (Fig. 3), statistically significant differences were found in hearing thresholds at extended high frequencies for ages 20–29 yr and 30–39 yr. This is consistent with other studies,[24,32] revealing that EHFA can be used as an early indicator of noise insult in mainly young adults exposed to noise. Finally, the prevalence of hearing loss at EHFA was significantly higher than CA among most civilian pilots (Table IV). Taken together, these findings provide robust evidence that EHFA is more sensitive to noise exposure than CA, which is consistent with the results of some previous studies.[19,23,33] This view has been demonstrated by animal studies which show that hair cells in the cochlear regions tuned to the very highest frequencies are the first focus of noise.[20,38] But there are still some studies which are opposite to our results.[4,18] Balatsouras et al. assessed EHFA in persons exposed to impulse noise and their study did not find any statistically significant threshold difference between CA and EHFA.[4] Kuronen could not find a significant difference between CA and EHFA among pilots, although he only assessed temporary threshold shift.[18] This may be explained by the fact that some types of noise are more likely to result in slowly progressive changes in the basal cochlea than other types of noise.[19]

The interaction between noise and age will always exist. Somma et al.[32] assessed cement workers and found that age appears to be a predominant factor compared with noise after 40 yr old. The authors recommended EHFA to be used in workers younger than 40 yr.[32] Another study by Macca et al. showed that age was the primary predictor and noise the secondary predictor of hearing thresholds in the high frequency range. The study suggested that EHFA could be a useful tool in assessing younger noise-exposed workers (under 30 yr of age).[21] We compared the hearing thresholds of subjects without noise exposure in each age group. The trend clearly shows that hearing thresholds (especially in extended high frequencies) decreased with advancing age and were more evident from the onset of 40 yr old, especially after 50 yr old (Fig. 1). Hence, we speculated that age may play an increasing role from 40 yr onwards.

As shown from the mean hearing thresholds of our study, the most frequently affected frequencies were 14 and 16 kHz for subjects ages 30–39. This result was in agreement with many other studies in the same age range. Mehrparva et al. found 14 and 16 kHz to be the frequencies with the highest threshold in CA and EHFA after exposure to noise.[23] Turkkahraman et al. also found 14 and 16 kHz to be more sensitive to noise.[35] Additionally, we also found 14 and 16 kHz for 20–29 yr, 11.2 and 12.5 kHz for 40–49 yr, and 11.2 and 10 kHz for 50–59 yr to be more sensitive to noise than other frequencies. So testing these frequencies only may give as much information as testing all the frequencies, reducing the time of the test.

Table III. Comparison of Mean Hearing Thresholds at Extended High Frequencies (9–20 kHz) dBHL Between Case and Control Groups with Any Value ≤20 dBHL in the Conventional Range.

	AGE	20–29		30–39	
kHz	GROUPS	CASE	CONTROL	CASE	CONTROL
9	Mean	6.1	4.63	10.36	12.14
	SD	6.88	7.32	7.93	6.99
	P	0.207 (n.s.)		0.318 (n.s.)	
10	Mean	4.31	3.15	11.25	11.07
	SD	6.23	7.91	10.15	9.64
	P	0.288 (n.s.)		0.817 (n.s.)	
11.2	Mean	3.06	1.48	13.57	12.14
	SD	7.86	8.61	10.96	5.79
	P	0.411 (n.s.)		0.957 (n.s.)	
12.5	Mean	7.5	3.15	18.04	11.79
	SD	9.3	9.68	14.8	8.46
14	Mean	11.53	4.72	24.46	9.29
	SD	12.06	13.68	19.55	8.53
	P	0.005		0.013	
16	Mean	16.39	5.28	28.57	5.71
	SD	20.16	19.14	21.77	12.54
	P	0.014		0.001	
18	Mean	15.69	7.96	27.14	15
	SD	16.70	14.71	9.95	16.87
	P	0.012		0.017	
20	Mean	4.72	0.65	7.86	7.5
	SD	7.07	6.45	3.95	6.43
	P	0.002		0.463 (n.s.)	

SD: standard deviation; *P*: *P*-value of the mean; n.s.: no significance.
The degrees of freedom of the case and control groups for age 20–29 are 17, 26; and 13, 6 for age 30–39.

EHFA has been successfully applied for detecting the early onset of drug-induced ototoxicity. With EHFA, physicians are able to find small hearing deficits in patients receiving drug treatment, thus adjusting therapeutic regimens in time.[11,15,16] This indirectly supports its potential usefulness in those working in noisy environments.

Table IV. Prevalence of Hearing Loss (%) in All Tested Frequencies (0.25–20 kHz) of the Case Group by Age Decade.

	HEARING LOSS (%)			
kHz	20–29 (*N* = 41)	30–39 (*N* = 41)	40–49 (*N* = 25)	50–59 (*N* = 27)
0.25	4 (4.9)	3 (3.7)	5 (10)	12 (22.2)
0.5	0 (0)	3 (3.7)	1 (2)	7 (13)
1	2 (2.4)	4 (4.9)	5 (10)	18 (33.3)
2	2 (2.4)	6 (7.3)	6 (12)	19 (35.2)
3	1 (1.2)	8 (9.8)	12 (24)	24 (44.4)
4	4 (4.9)	13 (15.9)	20 (40)	36 (66.7)
6	23 (28)	29 (35.4)	34 (68)	44 (81.5)
8	8 (9.8)	12 (14.6)	27 (54)	40 (74.1)
CA (0.25–8)	31 (37.8)	40 (48.8)	40 (80)	49 (90.7)
9	10 (12.2)	14 (17.1)	31 (62)	44 (81.5)
10	8 (9.8)	17 (20.7)	30 (60)	47 (87)
11.2	7 (8.5)	20 (24.4)	29 (58)	48 (88.9)
12.5	17 (20.7)	35 (42.7)	38 (76)	41 (75.9)
14	25 (30.5)	51 (62.2)	44 (88)	54 (100)
16	43 (52.4)	57 (69.5)	49 (98)	54 (100)
18	44 (53.7)	66 (80.5)	49 (98)	54 (100)
20	43 (52.4)	66 (80.5)	49 (98)	54 (100)
EHFA (9–20)	52 (63.4)**	77 (93.9)**	50 (100)**	54 (100)

Compared with CA, $^{**}P < 0.01$.

Studies on the possible role of EHFA as an early indicator regarding work-related hearing loss are much more limited. To the best of our knowledge, there are no more than 10 articles on this topic published during the past 20 yr. All of them highlighted the importance of EHFA and gave support to our study, which is the first to test the usefulness of EHFA in civilian pilots.

As for hearing conservation programs, airlines should provide pilots with hearing protection devices (HPDs), especially those able to protect pilots from high frequency impairment. When it comes to pilots, they should proactively begin use of or be refitted with HPDs and receive counseling about noise outside the cockpit. Lastly, pilots with hearing deficits identified by EHFA should be warned and undergo more intensive hearing monitoring.

There were some limitations in this study:

1. This study has the inherent limitation of all cross-sectional studies. To reach to this conclusion, prospective studies are required to prove civilian pilots with higher hearing thresholds in extended high frequencies have increased susceptibility to suffering from hearing loss in the conventional frequencies.
2. All of the pilots were men, so the results cannot be extrapolated to women, since female pilots in civil aviation are very few.
3. We did not use a speech-in-noise test to evaluate the actual communication capability of the pilots.

The data of this study showed that hearing thresholds deteriorate with increasing age, especially in EHFA. EHFA is more sensitive than CA and could be useful in detecting subclinical changes of hearing in civilian pilots. Measures should be taken earlier to prevent the progression of hearing loss into speech frequencies, which are more important in aviation safety. Suggestions on performing EHFA for civilian pilot screening should be based on longitudinal studies to show a progression of high frequency hearing impairment.

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