Middle Ear Resonance Frequency in Pilots and Pilot Candidates

Melisa Melek Tuncer; Seda Turkoglu Babakurban; Erdinc Aydin

BACKGROUND: Barotrauma is a frequent problem in aviation medicine. Eustachian tube dysfunction plays a critical role in the pathogenesis of barotrauma. Function of the Eustachian tube can be indirectly assessed by multifrequency tympanometry, which provides valuable information about the resistance and permeability of the middle ear in a wide frequency range. The aim of this study was to research whether multifrequency tympanometry could be used for assessing middle ear impairments in pilots.

METHODS: There were 140 pilots and pilot candidates between the ages of 20–55 with normal otoscopic examination who were evaluated by audiological test batteries. Body mass index values, flight hours, audiometric pure tone thresholds, tympanometry and multifrequency tympanometry test results were noted.

RESULTS: There was statistically significant decrease in the multifrequency tympanometry measurements of the left and right ears of the pilots with 200–3000 flight hours compared to pilot candidates, and similarly, the pilots with 3000–10,000 flight hours compared to pilot candidates.

DISCUSSION: Multifrequency tympanometry values changed between pilot candidates and pilots. However, the values of multifrequency tympanometry did not change due to flight hours. This test battery should not be used for follow up of pilots in the clinic.

KEYWORDS: Multifrequency tympanometry, barotrauma, aerotitis media, tympanometry, Eustachian tube.

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Barotrauma is one of the most common medical problems experienced in flight. The French physicist Jacques A. C. Charles, who carried out the first hydrogen filled balloon flight, described barotrauma in 1783, as he experienced ear pain during descent. Although the improvements in cabin technology after the Second World War have led to a decrease in its incidence, flight-related barotrauma still poses a serious problem with an incidence of 8–17%.[9,19] The most common complaints due to barotrauma are ear pain, feeling of fullness in the ears, tinnitus and hearing loss. When asked about an ear problem after flight, 65% of the children and 46% of the adults complained of pain and discomfort in their ears.[13] These symptoms occur more frequently in individuals with Eustachian tube dysfunction. The Eustachian tube essentially controls the ventilation of the middle ear cavity. However, qualitative and quantitative physiological parameters about gas transfer via the Eustachian tube are not fully understood yet.[16] Rosenkvist et al.[15] reported that every commercial pilot has an upper respiratory tract infection 1–2 times per year, while 37% of these pilots experience one or more barotrauma attacks. Nasal septal deviation, nasal mucosal congestion due to upper respiratory tract infections and allergies, nasal polyps, otitis media, adenoid vegetation, or other pathologies that lead to nasal or nasopharyngeal obstruction may all cause Eustachian tube dysfunction. Depending on the duration and the severity of the trauma, severe complications such as hemotympanum, tympanic membrane perforation, ossicular chain dislocation and consequent severe hearing loss, aerotitis media due to edematous middle ear mucosa, and fluid accumulation in the form of transudate in the middle ear can occur.[16]

Henry et al.[6] reported on a pilot who had a history of otitis media in his left ear in childhood and experienced a left

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tympanic membrane perforation after flying in the war zone with poor flight equipment and while he had an upper respiratory tract infection and ear block. That report suggests that a history of middle ear problems may be related to Eustachian tube dysfunction, which, in turn, may be aggravated by flight-related barotrauma and eventually cause complications. The changes in the middle ear caused by barotrauma should be monitored by test batteries. Multifrequency tympanometry can be a useful tool for this purpose.

Multifrequency tympanometry is a method that consists of tympanograms obtained with different probe tones between 226 Hz and 2000 Hz. High-frequency probe tones are more valuable for the diagnosis of middle ear pathologies that increase the stiffness of the system. In addition to static admittance, tympanometric peak pressure, external auditory canal volume, and tympanometric gradient parameters, which are measured by classical tympanometry that uses 220/226 MHz probe tone signals, multifrequency tympanometry separately measures the admittance of the middle ear system and determinants of admittance, and calculates static admittance (SA) at multiple frequencies, as well as middle ear resonance frequency.[12] In this sense, multifrequency tympanometry provides valuable information about the condition of middle ear structures and can be used as a practical and cost-effective tool in the differential diagnosis of middle ear diseases, including otosclerosis, partial or total separation of the ossicular chain, middle ear malformations, primary cholesteatoma, middle ear tumors, osteogenesis imperfecta, and fibrous dysplasia.

In this study, we aimed to assess the effect of flight hours on multifrequency tympanometry measurements, which is an indirect measurement of the integrity of the Eustachian tube and middle ear structures, and to search whether multifrequency tympanometry can be used for assessing middle ear impairments in pilots.

METHODS

Subjects

A prospective, controlled clinical study was designed and conducted at the Department of Otolaryngology, Baskent University, Ankara, Turkey. This study was approved by Baskent University Institutional Review Board and Ethics Committee (Project no: KA13/258) and supported by Baskent University Research Fund. Written informed consent was obtained from all participating subjects.

There were140 pilots and pilot candidates who were examined according to the Civil Aviation Act and selected to participate. Individuals who had normal otoscopic examination findings and no history of an ear, nose and throat related problem, including hearing, were included into the study.

Study groups consisted of pilots who had 200–3000 h (Group I), and 3000–10,000 h (Group II) of flight experience, respectively. Individuals who were candidates for flying and had no flying experience constituted the control group. Both ears of the all participants were tested.

Equipment

Pure tone audiometry was performed with an AC-40 clinical audiometer (Interacoustics A/S, Middelfart, Denmark) in quiet rooms, in accordance with the Industrial Acoustics Company (IAC) standards. The speech understanding threshold test was carried out using three-syllable word lists from our clinic, and the speech discrimination test was carried out by using phonetically balanced monosyllabic word lists (FD-300). Pure tone thresholds were evaluated according to F1 and F2 age-related hearing threshold tables determined by OSHA (Occupational Safety and Health Administration).

Immitancemetric evaluation of all individuals was performed by using Grason-Stadler TympStar Version 2 electroacoustic immitancemeter (Grason-Stadler, Eden Prairie, MN).

Procedure

All participants were examined by an Ear, Nose and Throat specialist. Then, pure tone audiometry was applied to all of the participants to determine the hearing thresholds. Then the speech understanding threshold test was administered.

Immitancemetric evaluation of all individuals was performed after audiometric evaluation. First, tympanograms and static admittance (SA) were recorded by using a 226 Hz probe tone. Tympanograms were recorded by changing air pressure at the rate of 200 daPa $\cdot$ s^{-1} between +200 and -400 daPa. Then, multifrequency tymanometry measurements were carried out in two stages. In the first stage, standard tympanometry parameters such as SA, tympanometric peak pressure, and gradient measurements were carried out by fixed frequency probe tone and changing air pressure between +200 and -400 daPa. In the second stage, middle ear resonance frequency was determined by fixed pressure and changing the frequency with 50 Hz intervals between 250 and 2000 Hz.

The groups were compared in terms of age, body mass index, flight hours, pure tone thresholds, tympanometry, and multifrequency tympanometry measurements.

Statistical Analysis

For discrete and continuous variables, descriptive statistics (mean, standard deviation, median, minimum value, maximum value, and percentile) were given. In addition, the homogeneity of the variances, which is one of the prerequisites of parametric tests, was checked through Levene's test. The assumption of normality was tested via the Shapiro-Wilk test. To compare the differences between the two groups, the Student's *t*-test was used when the parametric test prerequisites were fulfilled, and the Mann Whitney–*U*-test was used when such prerequisites were not fulfilled. To compare the differences between three and more groups, one-way analysis of variance was used when the parametric test prerequisites were fulfilled, and the Kruskal Wallis test was used when such prerequisites were not fulfilled. The Bonferroni correction method, which is a multiple comparison test, was used to evaluate the significant results concerning three and more groups. The Chi-square test was used for determining the relationships between two discrete variables. When the expected sources were less than 25%, values were determined through the Monte Carlo Simulation Method in order to include such sources in analysis. The data were evaluated via SPSS 20 (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.). $P < 0.05$ and $P < 0.01$ were taken as significance levels.

RESULTS

There were 51 pilots (mean age, 31.4 ± 5.9 yr; range, 21–49 yr) in Group I, and 45 pilots (mean age, 40.3 ± 6.2 yr; range, 28–52 yr) in Group II, respectively. The control group was 44 pilot candidates (mean age, 22.6 ± 4.6 yr; range, 19–36 yr). There was significant difference between groups in terms of age ($P < 0.001$) and body mass index ($P = 0.01$).

The most common tympanogram was type A for 81.8% of the left and right ears in the control group. In Group I, 74.5% of the left, and 72.5% of the right ears gave a Type A tympanogram. In Group II, 69.7% of the left, and 76.4% of the right ears gave a Type A tympanogram. When the groups were compared with each other, the only statistically significant difference was found between the left ears of Group II and the controls ($P = 0.02$). It was found that as the flight hours increased, the frequency of the Ad tympanogram was increased (in pilot candidates 13.6% of the left, 18.2 of the right ears; in Group I 19. 6% of the left, 21.6% of the right ears; in Group II 35.6% of the left, 22.2% of the right ears). However, there was no statistically significant difference between the groups and ears (**Fig. 1** and **Fig. 2**). In terms of the acoustic reflex, there was no statistically significant difference between the groups and ears.

There was no statistically significant difference between the audiometric findings of the left ears in Group I and the controls at the frequencies of 250 Hz, 500 Hz, 1 kHz, 2 kHz, 6 kHz, and 8 kHz. However, pure tone thresholds at 3 kHz ($P = 0.01$) and 4 kHz ($P = 0.04$) were higher in Group I. There was also no statistically significant difference between the audiometric findings of the right ears in Group I and the controls at the frequencies of 250 Hz, 500 Hz, 1 kHz, 2 kHz, 3 kHz, 6 kHz, and 8 kHz. However, pure tone thresholds at 4 kHz were higher in Group I ($P = 0.03$). There was a statistically significant difference between the audiometric pure tone thresholds of Group II and the controls for both the left and right ears, at all frequencies [250 Hz ($P < 0.001$), 500 Hz ($P < 0.001$), 1 kHz ($P < 0.001$), 2 kHz ($P < 0.001$), 3 kHz ($P < 0.001$), 4 kHz ($P < 0.001$), 6 kHz ($P < 0.001$), and 8 kHz ($P < 0.001$) for left ears; 250 Hz ($P = 0.03$), 500 Hz ($P < 0.001$), 1 kHz ($P = 0.03$), 2 kHz ($P < 0.001$), 3 kHz ($P < 0.001$), 4 kHz ($P < 0.001$), 6 kHz ($P = 0.01$), and 8 kHz ($P < 0.001$) for right ears]. There was a statistically significant difference between the pure tone thresholds of left ears in Group I and Group II, at all frequencies except 500 Hz [250 Hz ($P < 0.001$), 500 Hz, 1 kHz ($P < 0.001$), 2 kHz ($P < 0.001$), 3 kHz ($P < 0.001$), 4 kHz ($P = 0.02$), 6 kHz ($P < 0.001$) and 8 kHz ($P < 0.001$)]. There was also a statistically significant difference between the pure tone thresholds of the right ears in Group I and Group II, at all frequencies except 4 kHz [250 Hz ($P < 0.001$), 500 Hz ($P = 0.04$), 1 kHz ($P = 0.03$), 2 kHz ($P = 0.02$), 3 kHz ($P = 0.01$), 6 kHz ($P = 0.01$) and 8 kHz ($P = 0.01$)].

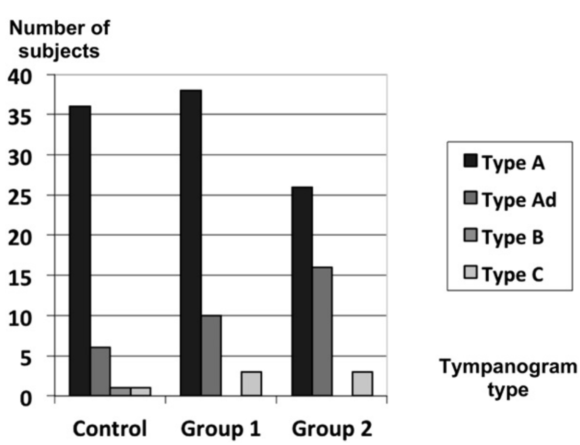

Fig. 1. Left ear classical tympanogram results of the groups (number of subjects is in the y axis).

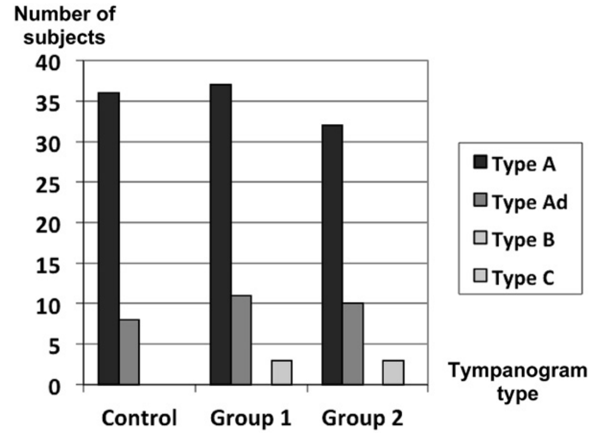

Fig. 2. Right ear classical tympanogram results of the groups (number of subjects is in the y axis).

Mean (± SD) of middle ear resonance frequency values in the left/right ear were 862.50 ± 104.06 / 882.95 ± 162.08 in the control group; 605.88 ± 104.71 / 609.21 ± 122.42 in Group I; and 547.77 ± 108.68 / 606.66 ± 230.75 in Group II. There was a statistically significant difference according to the Kruskal Wallis and Bonferonni Dunn tests between the mean middle ear resonance frequency values of the groups for left ($P = 0.01$) and right ears ($P = 0.01$). Then we divided the subjects of three groups into two other groups according to the middle ear resonance frequency values between 0 and 758.4 or 758.4+ for left ears, and 0 and 720.8 or 720.8+ for right ears [758.4 was the mean middle ear resonance frequency value (Hz) – SD of the left ears of the control group; 720.8 was the mean middle ear resonance frequency value (Hz) – SD of the right ears of the control group]. Middle ear resonance frequency values of 61.4% of the left ears of the control group, 98% of the left ears of Group I, and 100% of the left ears of Group II were in the 0–758.4 Hz group. Middle ear resonance frequency values of 56.8% of the right ears of the control group, 100% of the right ears of Group I, and 95.6% of the right ears of Group II were in the 0-720.8 Hz group. Middle ear resonance frequency values for both left and right ears in Group I were found to be lower when compared to those in the control group. There was a statistically significant difference in terms of the percentage of the subjects of left/right ear of the controls and Group I ($P < 0.001$, $X^2 = 26.27$, df:1 for left ears; $P < 0.001$, $X^2 = 18.43$, df:1 for right ears). Similarly, there was a statistically significant decrease in the resonance frequency of both ears in Group II compared to the controls. There was statistically significant difference in terms of the percentage of the subjects of left/right ears of the controls and Group II ($P < 0.001$, $X^2 = 14.21$, df:1 for left ears; $P < 0.001$, $X^2 = 15.27$, df:1 for right ears). However, there was no statistically significant difference between the resonance frequency values of Group I and II characterized by their hours of flight ($P = 0.517$, $X^2 = 8.69$, df:1 for left ears; $P = 0.458$, $X^2 = 4.58$, df:1 for right ears) (**Fig. 3** and **Fig. 4**).

DISCUSSION

Barotrauma is still the most common medical problem experienced in flight.[19] Structural and/or functional changes that occur in the middle ear due to flight may not be detected with otoscopic examination, if the tympanic membrane is intact. In this case, audiological tests such as audiometry, tympanometry, and multifrequency tympanometry can help to reflect these changes. In this study, we looked for the effects of flight on pure tone audiometry, tympanometry, and multifrequency tympanometry results, as an indirect measure of the middle ear function in pilot candidates and pilots. We found that as the flight hours increased, the risk of hearing loss was increased. In addition, we showed that as the flight hours increased, the frequency of an Ad tympanogram was increased. However, we did not demonstrate the effect of flight on the multifrequency tympanometry.

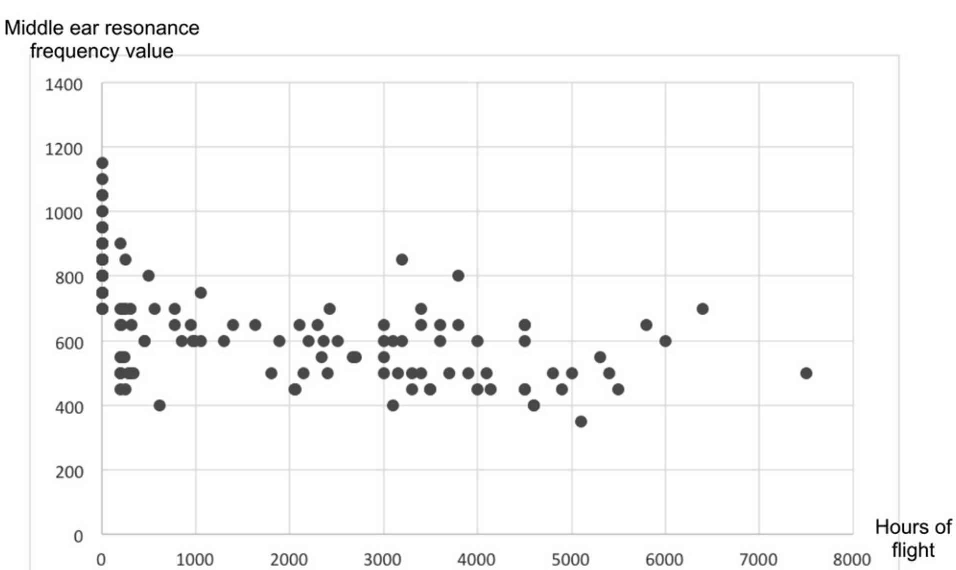

Fig. 3. Middle ear resonance frequency values of the left ears of all the groups (x axis: hours of flight, y axis: middle ear resonance frequency values of the left ear).

One of the most commonly performed audiological tests in pilots is pure tone audiometry.[1,5] Satish et al.[17] reported that noise-induced hearing loss mostly affects pure tone hearing thresholds at 4 kHz and 6 kHz in pilots. The data obtained in our study show that a decrease in pure tone hearing thresholds was significant at 3 and 4 kHz in pilots with 200–3000 flight hours, while it was significant at all the frequencies in the pilots with 3000–10,000 flight hours. In order to eliminate the effect of age, we used age-related hearing thresholds in F-1 and F-2 tables designated by OSHA, and found that as the flight hours increased, both hearing loss and affected frequencies were increased. This finding is in concordance with the reports in the literature.[10,14,24] Hearing loss in pilots could be related with changes in the middle ear due to barotrauma, and changes in the inner ear due to acoustic trauma. Pilots with a history of ear problems such as otitis media in their childhood could be more easily affected by barotrauma and acoustic trauma. Raynal et al.[14] showed that pilots who had otitis media attacks in their childhood had decreased hearing thresholds, especially in their left ears. In our study, pilots with 200–3000 flight hours had hearing loss especially in their left ears. The reason for this side asymmetry may be the exposure of the left ear to the acoustic trauma of the propeller.

Tympanometry is also frequently used to evaluate the middle ear in aviation medicine. De Hayne[4] reported that 2/3 of pilot candidates with negative pressure in their middle ear and 1/3 of pilot candidates with normal middle ear pressure had experienced barotrauma. This suggests that tympanometry alone is not a reliable test in pilots. Tian[20] reported that most of the pilots with normal ears and pilots with chronic aerotitis media had a Type A tympanogram. Type B and Type C tympanograms were characteristic findings of acute aerotitis media.[20] In our study, Type A and Type Ad tympanograms were the most frequently determined types, whereas Type B and Type C tympanograms were rarely determined in all three groups. We found that as the flight hours increased, the frequency of the Ad tympanogram was increased. However, in terms of the tympanogram type, there was a statistically significant difference only between the left ears of the pilot candidates and pilots with 3000–10,000 flight hours. A statistically significant difference was not detected between the groups in terms of acoustic reflexes. According to these findings, there was no statistically significant correlation between the tympanometry results and flight hours. In addition we could not suggest that multifrequency tympanometry may be more valuable for assessing the effect of flying on hearing according to our data.

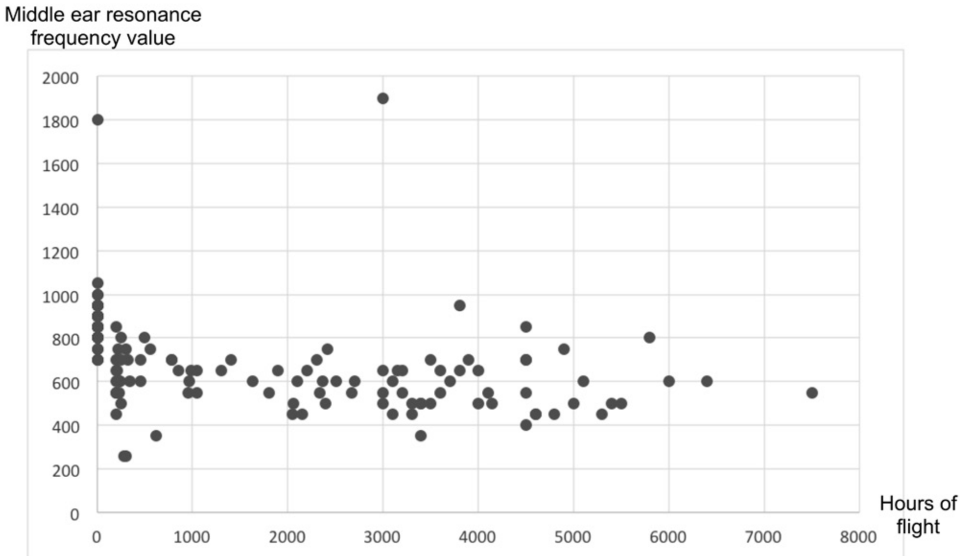

Fig. 4. Middle ear resonance frequency values of the right ears of all the groups (x axis: hours of flight, y axis: middle ear resonance frequency values of the right ear).

Although multifrequency tympanometry is an advantageous test, it has not been used widespread in the clinical application. One of the reasons for that may be the lack of sufficient data.[12]

Colletti[3] demonstrated that three types of tympanogram could be seen in people with a normal tympanic membrane. He obtained V-shaped tympanograms at low frequencies, W-shaped tympanograms at middle frequencies near the resonance frequency, and inverted V shaped tympanograms at higher frequencies.[3] In subjects with normal ear function, a W pattern can be obtained between 650 and 1400 Hz. Different middle ear pathologies such as otosclerosis, broken ossicular chain, serous otitis media, and cholesteatoma or previous surgeries such as stapedectomy or myringoplasty affect the frequency range in which a W pattern can be obtained.[2,3] This finding is of particular importance since it allows the use of multifrequency tympanometry for differential diagnosis when the tympanic membrane appears normal. Thereby it can be determined whether multifrequency tympanometry can detect ear problems in pilots.

Structural properties of the external and middle ear vary according to age, environmental and genetic factors. These differences affect the admittance of the middle ear and cause variations in the normal multifrequency tympanometry values.[18]

Lutman[11] found the average middle ear resonance frequency was 871 Hz in 67 normal ears and explained the theoretical mechanism of the components of the middle ear admittance. Wada et al.[23] found the normative value of middle ear resonance frequency around 1000 Hz while Valvik et al.[22] found it to be 1049 ± 261 Hz in a larger group of patients. In our study, mean middle ear resonance frequency was determined as 862.5 Hz and 882.95 Hz in the left and right ears of the pilot candidates, respectively.

Lai et al.[8] evaluated the standard tympanometry and multifrequency tympanometry findings of patients with otitis media with effusion and normal populations. The authors demonstrated that multifrequency tympanometry was more sensitive and more objective for the diagnosis of otitis media with effusion in adults.[8] This suggests to us that multifrequency tympanometry may be more useful in diagnosing barotrauma induced acute aerotitis media than standard tympanometry. In our study, we did not find any difference in terms of tympanometric findings but multifrequency tympanometry findings showed statistically significant changes between the pilot candidates and the pilot groups. There was a statistically significant decrease in the resonance frequency of both ears in Group I and II compared to controls. However, there was no statistically significant difference in the values of multifrequency tympanometry from 200 h to 8000 h of flight. Thus we could not suggest that multifrequency resonance tympanometry is a sensitive tool to assess middle ear subtle impairments that could occur with increasing hours of flight. Holt et al.[7] and Uchida et al.[21] did not observe a significant effect of age on multifrequency tympanometry measurements. Thus, we did not assess the effect of age on middle ear resonance frequency.

We did not demonstrate the effect of middle ear resonance frequency on flight hours. The relation between the flight hours and the middle ear resonance frequency should be further studied and routine use of multifrequency tympanometry in the follow up of pilots should be discussed.

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