Molded Communication Earplugs in Military Aviation

Taija M. M. Lahtinen; Tuomo K. Leino

INTRODUCTION: Radio communication remains important for the delivery of safety-critical information in military aviation. Pilots are exposed to high noise levels. Noise attenuation provided by certain helmets is not sufficient, and resulting noise exposure can deteriorate operational effectiveness and flight safety. A need for hearing protection that enables efficient communication is obvious, especially for fighter and helicopter pilots. One possible solution for this issue is molded communication earplugs (m-CEP). Data about the advantages and disadvantages of m-CEPs are limited.

METHODS: To determine the usage rates, advantages, disadvantages and pilot opinions about m-CEPs, an anonymous survey study including 31 questions was conducted in fighter, fighter trainer, helicopter, and transport aircraft units of the Finnish Defense Forces.

RESULTS: Of the pilots who responded, 136 (93%) had used or tried m-CEPs and 90 (62%) were currently using them. There are many benefits to m-CEPs: they seem to enhance experienced speech intelligibility, since 85% of the pilots who had experience about them reported improved speech intelligibility under difficult hearing conditions, and 93% would recommend them to other pilots. It seems m-CEPs provide equal benefits to pilots with and without current hearing problems. They were also considered better than previously used hearing protectors. Still, problems were common: 82% of the pilots reported m-CEP related drawbacks, of which technical problems and discomfort issues were the most prevalent.

DISCUSSION: Most military pilots hold a positive opinion on m-CEPs and are willing to recommend their use. Technical problems and discomfort issues are, however, relatively common.

KEYWORDS: hearing protection, earplugs, pilot, noise.

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Radio speech communication is a key flight safety factor. The majority of safety-critical information affecting flight is delivered via radio, and radio communication also contributes to situation awareness. Crew resource management also requires radio communication in both civil and military type flying. One of the most important factors that reduces communication is noise. Noise exposure of military pilots is high: depending on aircraft type, it can reach 95–115 dB in military aircraft cockpits.[4,6,7] In the future, noise levels are expected to increase since noise levels produced by next-generation high performance aircraft engines can attain 110–150 dB.[13] Noise levels this high are a risk factor for hearing loss. Also, noise has well-known adverse psychological effects on, e.g., concentration and workload.[17] Because flying a modern military fighter aircraft is a very challenging task that requires the full use of the crew's information processing capacity, all factors that disturb this cognitive capacity can jeopardize flight safety. Recent data suggests that the combination of flight workload and poor communication signal quality leads to decrements in flight performance.[2]

Although flight helmets attenuate noise, noise levels inside the helmet at the ear canal entrances can attain 87–91 dB in the aircraft and flight helmet types used by the Finnish Air Force.[7] The Joint Helmet Mounted Cueing System (JHMCS) helmet has been in operational use in Finland for approximately 5 yr and, due to a lighter core, it has a lower sound attenuation capability than earlier helmets. The noise level inside the JHMCS helmet at the ear canal entrance is 96 dB.[3] Pilots have reported problems with noise and missing radio signals when wearing the JHMCS helmet without any extra hearing protection.[9] In Finland, the

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Gentex ACS and Alpha helmets are also used in addition to the JHMCS helmet. According to noise level measurements conducted by the Finnish Institute of Occupational Health,[3] noise levels inside these helmets at the ear canal entrance are 89 dB for the Gentex ACS helmet and 92 dB for the Alpha helmet. Flight helmets with active noise reduction (ANR) are currently not in use in Finland. Additional hearing protection, especially for use with the JHMCS helmet, is needed to prevent hearing loss, and hearing protection devices also need to enable efficient radio communication in a tactical fighter environment.

In a survey conducted among Finnish military pilots before the Finnish Defense Forces began using JHMCS,[8] a need for additional hearing protection was obvious. Radio speech communication problems were reported to be relatively common, occurring during 14% of flight time. High background noise was one of the most prevalent reported problems. Pilots' willingness to use additional hearing protection was also shown to be very high, at 93%, indicating a need for improved hearing protection.[8]

One solution that would improve both hearing protection and the quality of radio communication is the communication ear plug (CEP). The first CEPs consisted of a miniature transducer and a foam ear plug.[13] Nowadays, several manufacturers offer different CEP types, and the custom-molded type (custom-molded communication ear plug or m-CEP) is being used in increasing numbers. During rapid altitude changes typical of fighter aircraft flying, it is also crucial that the m-CEP allows pressure to equalize between the tympanic membrane and the ear plug to prevent external ear barotrauma. In the m-CEP used in Finland, the system consists of a custom-molded silicone ear plug which includes a small loudspeaker. The loudspeaker, connected to the helmet via cable, delivers communication from the aircraft's communication system to the pilot's ear. The custom-molded plug includes a pressure equalizing vent with an acoustic filter which enables pressure equalizing.[3]

Other possible hearing protection solutions include standard earplugs, headsets, and ANR systems. Standard earplugs provide sound attenuation ranging from 10–30 dB depending on the frequency. Even though their attenuation capacity may be good, they also reduce the communication signal, and may create trapped air between the earplug and tympanic membrane and therefore they are not ideal for military flying. Headsets can provide good (up to 30–35 dB) attenuation on frequencies higher than 500 Hz, but on low frequencies their attenuation capacity is not sufficient, and they also lack head protection and other functions provided by flight helmets.[11] Thus, from these alternatives, ANR systems seem to satisfy all requirements. Their use in helmets and earmuffs is increasing and they have been shown to be functional in different aircraft types.[12]

There is evidence that CEPs may have benefits compared to other hearing protection devices. In a study by Ribera et al.,[14] three different sound attenuation devices (flight helmet only, flight helmet modified with active noise reduction, and flight helmet with a CEP) were compared in terms of providing protection against helicopter noise. Test subjects included both pilots with normal hearing and those who held a waiver for hearing loss. Ribera discovered that CEPs improved speech intelligibility in a noisy environment when compared to the flight helmet only configuration. Improvement was particularly marked among pilots who held waivers due to hearing impairment, as indicated by the fact that many of them were able to achieve normal performance in speech intelligibility tests when wearing CEPs. ANR systems were also reported to benefit pilots with hearing loss.

Despite their advantages, CEPs appear to have characteristics that make pilots unwilling to use them. Koda[6] reported in his abstract that in a survey among F-22 Raptor pilots, 15.6% of the respondents preferred not to use CEPs. The number of problems and discomfort issues was reported to be high: as many as 81% of the respondents had problems with the CEPs, and 78% reported discomfort issues, which were the most common reason for not using CEPs. Steinman[15] stated in his report on a study in which 14 pilots compared three CEP systems that even though speech intelligibility and noise attenuation were improved, the pilots experienced problems in, e.g., adapting to the use of the devices. They also found friction noise caused by clothing contacting the connecting cable disturbing.

There is a limited amount of reported data from military pilots about the advantages and disadvantages of CEPs. Therefore, it is important to discover factors behind the identified user problems in order to obtain an improvement in the usage rate of hearing protection. After our initial speech communication survey,[8] the Finnish Defense Forces has begun to use m-CEPs. In this study we wanted to discover how often m-CEPs are used, to examine whether pilots find them useful when carrying out their duties, and to identify any m-CEP associated problems pilots may have encountered.

METHODS

A survey on the use of m-CEPs was conducted in the F/A-18 Hornet fighter, Hawk fighter trainer, helicopter, and transport aircraft units of the Finnish Defense Forces. The questionnaire was answered anonymously. The administration of the questionnaires at unit level was organized by aviation safety officers. Helmet types available for pilots are the JHMCS, Gentex ACS, and Alpha helmets. The study was approved in advance by the Finnish Defense Forces Medical Research Register and the Air Force Command. The study is a part of a research approved by the ethical review board of the Northern Ostrobothnia Hospital District, Finland.

Questionnaire

The questionnaire, although specifically constructed for this study, included several items from our previous survey.[8] There were 31 questions on the questionnaire. Of them, 12 probed background information (age, gender, squadron or battalion, past and current aircraft types, flight experience, and ear and hearing problems both past and current), 5 questions were aimed at identifying radio communication problems in general, and 14 were written to look at m-CEP related issues. The questions are presented in **Table I**.

Table I. Survey Questions.

BACKGROUND INFORMATION
1. Gender.
2. Age.
3. Mother tongue and aviation language.
4. How long have you worked in the Finnish Defence Forces?
5. Current squadron/battalion.
6. Current task (active pilot/headquarters/other).
7. Flight duty percentage of working time.
8. Current aircraft type.
9. Aircraft types to which you have type training.
10. Flight hours (total and on different aircraft types) and during last 12 mo, 3 mo, 1 mo.
11. Current hearing and ENT problems: Do you currently have…
Problems with hearing
Hearing impairment
Ear disease
Noise exposure during leisure time
Problems in ear pressure equalization
Tinnitus
Hyperacusis
Leisure-time noise exposure:
Do you use hearing protection during leisure time? (How often? Percentage of exposure time.)
12. Previous hearing and ENT problems: Have you previously had…
Recurrent otitis in childhood (how many?)
Solvent exposure
Noise exposure
Hospital treatment because of any head trauma
Any previous hearing deficit
Noise exposure during leisure time
Have you used hearing protection during leisure time noise exposures? (How often? Percentage of exposure time.)
RADIO COMMUNICATION ISSUES IN GENERAL
13. How often do you experience problems in aviation radio communication (percentage of flight time)?
14. Radio speech communication problems occur most often in which flight types (basic training flights/training flights/combat training flights/ support flights/other)?
15. How often does background noise affect radio communication (never/rarely/quite often/almost always)?
16. What hearing protection do you usually use when flying (headset only/flight helmet only/flight helmet + ear plugs/flight helmet + m-CEP/other)?
17. How often do you use hearing protection when working in noisy environment?
QUESTIONS ABOUT m-CEPS
18. Do you use m-CEPs? (If not, why?)
19. How often do you use m-CEPs? (Percentage of flights)
20. How long have you used m-CEPs?
21. Have you had any problems with m-CEPs? (Yes/No) If yes, report all problems you have experienced from the list below:
Poor fitting – helmet causes pressure
Poor fitting – discomfort or pain in outer ear
Poor fitting – discomfort or pain inside of ear
Poor fitting – the plug feels loose or does not stay in place
Problems with pressure equalization while using
Problems with wiring or connectors
Other (describe)
22. Have you experienced that m-CEP use has been factor in incidents or hazardous situations? (Yes/No, if yes, describe the situation.)
23. Have you experienced physiological incidents because of m-CEP? (Yes/No, if yes describe the situation)
24. Does m-CEP improve speech intelligibility in difficult hearing situations (Yes/No)
25. Have you noticed change in occurring of tinnitus after you began using m-CEP (tinnitus has decreased/no change or I do not have tinnitus/tinnitus has increased)?
26. Have you had problems in maintenance of m-CEPs? (Yes/No)
27. Has pressure equalization valve in your m-CEPs gotten blocked in use? (Yes/No)
28. How many ear pieces have sustained damage or failure during your m-CEP use?
29. Have you experienced technical problems in the wiring of the m-CEP and helmet? (Yes/No)
30. Would you recommend m-CEPs to your fellow airmen or subordinates? (Yes/No)
31. When comparing m-CEP to other hearing protection devices, do you find m-CEP:
Better/equal/worse than flight helmet only
Better/equal/worse than conventional ear plugs only
Better/equal/worse than headset only

Statistical Analysis

For statistical analysis, Excel and SPSS 16.0 were used. When necessary, pilots flying fighters, transports, and primary trainers were put together in a "fixed-wing pilots" group, while helicopter pilots formed their dedicated group. For analyzing certain questions, the pilots were divided into age groups (20-29 yr, 30-39 yr, and 40-49 yr; the sole subject over 50 yr of age was excluded from age group comparisons). For analyzing the amount of current hearing problems, a variable labeled "any current hearing problems" was calculated. A pilot was put in this group if he had reported current problems with hearing, hearing impairment, or any ear disease. During this survey, only one m-CEP type (Omara®, Amplifon, Lausanne, Switzerland) was in use in Finland. When analyzing questions addressing m-CEP related issues, only answers from pilots who had used or tried m-CEPs were included, and answers from pilots who did not have experience with m-CEPs were excluded. Descriptive statistics were run to determine how often the subjects used m-CEPs, how common radio communication problems were, and for the yes/no questions. A Chi-squared test was used to calculate differences for yes/no and ordinal scale questions. Descriptions about incidents or hazardous situations were analyzed qualitatively. *P*-values less than 0.05 were considered statistically significant.[1]

RESULTS

Altogether 146 pilots (127 fixed-wing and 19 helicopter pilots) returned the questionnaire. The response percentage was 59%. The mean age of the respondents was 32 yr (range 23–51). The results for background questions are presented in **Table II**. Older pilots reported experiencing current hearing problems more often than younger pilots. The prevalence of any current hearing problem was 13% with pilots between 20 and 29 yr, 24% with pilots ages 30-39 yr, and 44% in the 40-49 yr age group. The difference between the age groups was statistically significant (Chi-squared test $P = 0.01$). No difference was noted between the age groups in current leisure-time noise exposure, pressure equalizing problems, tinnitus, or hyperacusis.

The pilots were asked to report what kind of hearing protection they usually use during flight duties (question 16). The answers were distributed as shown in **Fig. 1**. M-CEPs had been used or tried by 93% (136 pilots) of the respondents (questions 18 and 20). Currently they were being used by 62% of the pilots (63% of the fixed-wing pilots and 53% of the helicopter pilots). The pilots who were using m-CEPs used them very often (question 19), on 90% of flights on average (range 5–100%). Mean duration of m-CEP use was 2 yr 9 mo (range 2-54 mo).

M-CEPs were reported to enhance experienced speech intelligibility. Of the pilots who had used or tried m-CEPs, 85% reported that they had improved speech intelligibility under difficult hearing circumstances (question 24). Comparing the fixed-wing and helicopter pilots, it appears that the helicopter pilots found this improvement slightly more significant, with 100% of the helicopter pilots and 83.5% of the fixed-wing pilots, respectively, reporting an improvement. However, the difference between the groups did not reach statistical significance (Chi-squared test $P = 0.08$). There was no difference in the experienced speech intelligibility improvement between pilots with and without current hearing problems (Chi-squared test $P = 0.88$), nor between pilots in different age groups (Chi-squared test $P = 0.23$).

It also appears that m-CEPs may have a preventive effect on postflight tinnitus. Of the 115 pilots who answered question 25 (Have you noticed a change in the occurrance of tinnitus after you began using m-CEP?), 30% reported that postflight tinnitus had decreased since they had started using m-CEPs. None of the pilots reported an increase in postflight tinnitus. No change or no tinnitus at all was reported by 70% of the pilots. There was no difference in the effects of m-CEPs on postflight tinnitus between pilots who reported current hearing problems and ones who did not (Chi-squared test $P = 0.49$), or between the different age groups (Chi-squared test $P = 0.31$).

Of the pilots who had used or tried m-CEPs, 93% would recommend them to their fellow airmen or subordinates (question 30). M-CEPs were also considered better than the previously used hearing protectors (see **Fig. 2**). Despite the positive aspects, however, many pilots had also encountered problems with the m-CEPs. Of pilots who had used or tried m-CEPs, only 18% reported no problems with the device, whereas 82% reported that they had encountered problems (question 21). The most commonly reported problems and their prevalence are shown in **Fig. 3**.

As reported above, 62% of the pilots were currently using m-CEPs. When nonusers (the remaining 38%) were asked why they were not using the device (question 18), the answers were distributed as shown in **Fig. 4**. The main reasons were discomfort issues and the device being faulty or undergoing maintenance.

Of the pilots who had used or tried m-CEPs, 46% reported having experienced technical problems in the wiring of the m-CEP (question 29) and 43% with maintenance of the device (question 26). The pressure equalization vent appears to be functional since only 5% reported that it had been blocked (question 27). The amount of damaged or broken ear pieces was zero for 46% of the users, one for 37%, two for 14%, and three or more for 3% of the users (question 28).

The pilots were also asked to report any incidents or hazardous situations that in their opinion were caused by a problem with or a failure of the m-CEPs, and also to report any in-flight physiological incidents associated with m-CEP use (questions 22-23). Altogether nine incidents or hazardous situations were reported (by 7% of pilots who had used or tried m-CEPs). In seven of these cases, a malfunction or a disturbance in m-CEP signal had rendered radio communication inaudible, at least momentarily. One incident involved an attempt to adjust the m-CEP fitting, which caused the pilot to use a wrong switch. Two in-flight physiological incidents were reported: one ear pain (vent malfunction) and one ear canal barotrauma associated with a hooded immersion suit.

Table II. Background Question Results.

	RESPONSE (RANGE)	*N*
Male	100%	146
Mother tongue		
Finnish	99%	145
Swedish	1%	1
Aviation language		
English	96%	140
Finnish	4%	6
Worked in the Finnish Defense Forces	mean 11 yr (1–29)	142
Current task		
Active squadron/battalion pilot	85%	121
Staff/headquarters pilot	11%	16
Other	4%	6
Flight duty percentage of working time	mean 63% (0–100%)	145
Current aircraft type		
Fighter	78%	108
Transport/primary trainer	9%	12
Helicopter	13%	19
Total flight hours	mean 1254 (180-3600)	143
Any current hearing problems		
No	77%	113
Yes	23%	33
Current leisure-time noise exposure		
No	80%	116
Yes	20%	30
Current pressure equalizing problems		
No	89%	130
Yes	11%	16
Current tinnitus		
No	73%	106
Yes	27%	40
Current hyperacusis		
No	92%	133
Yes	8%	12
Previous recurrent otitis in childhood		
No	79%	115
Yes	21%	31
Previous solvent exposure		
No	99%	145
Yes	1%	1
Previous noise exposure		
No	93%	132
Yes	7%	10
Previous hospital treatment because of any head trauma		
No	96%	140
Yes	4%	6
Any previous hearing deficit		
No	90%	131
Yes	10%	15
Previous noise exposure during leisure time		
No	75%	110
Yes	25%	36

In responses about radio communication issues in general (questions 13-16), the prevalence of perceived in-flight communication problems (as an estimate of problems in percentage of flight time) was reported to be 14% on average (range 0–100%, median 10%). The flight type during which the subjects experienced the most communication problems varied depending on the pilot group. For 53% of the fixed-wing pilots, this was air combat training flights, while 53% of the helicopter pilots encountered the most problems in this area during basic training flights in the MD500 light helicopter. Background noise (question 15) affected speech communication quite often for 26% of the pilots and almost always for 6% of the pilots; the remaining 68% of the pilots considered it a problem never or rarely. There were no differences between fixed wing and helicopter pilots (Chi-squared test $P = 0.28$).

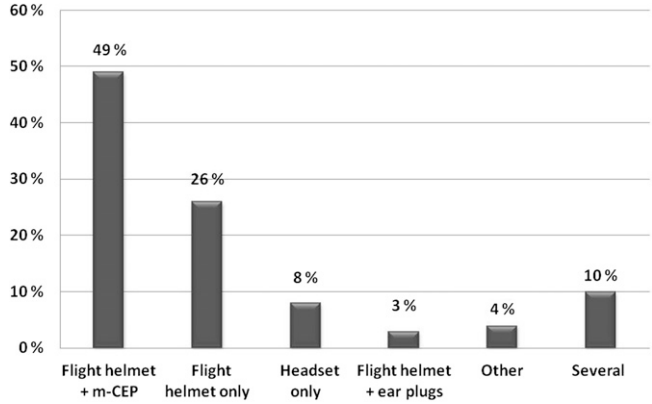

Fig. 1. Hearing protectors most commonly used in flight duties, $N = 146$ (question 16).

DISCUSSION

This study shows that military pilots have recognized the advantages of using m-CEPs in flight. Almost all subjects who had experience with m-CEP use would have recommended the system to their fellow airmen. Good communication quality and better signal-noise ratio are key factors for efficacious radio communication in an operational environment. Of the subjects who had used or tried m-CEPs, 85% reported that they had improved speech intelligibility under difficult in-flight hearing circumstances. The subjects also considered m-CEPs more functional in terms of hearing protection than previously used hearing protection devices. However, complaints about m-CEPs were common. Discomfort and technical disturbances were the top issues. Technical reliability was especially poor since mean m-CEP use time was less than 3 yr and several devices had suffered faults and malfunctions at the time of the survey. M-CEPs are maintained by the pilots themselves, which may be a factor behind the high failure rate. The delivery times of new m-CEPs to replace failed devices were also excessively long.

This study shows that the benefits of m-CEPs seem to be equal both for pilots with and without current tinnitus and/or current hearing problems since both groups reported an improvement in speech intelligibility. However, some previous studies[14] indicate that CEPs are particularly beneficial for pilots with hearing impairments and, therefore, those pilots should be encouraged to wear m-CEPs. Furthermore, the subjects reported less postflight tinnitus, which may correlate with better noise protection provided by the device. On the other hand, synthetic voice alerts (e.g., "altitude, altitude") are not communicated via m-CEP. The effect of the reduction in

Fig. 2. Pilots' opinion about m-CEPs compared to other hearing protectors (question 31). M-CEP vs. helmet alone, $N = 132$; m-CEP vs. ear plugs, $N = 115$; m-CEP vs. headset, $N = 90$.

these synthetic sounds while using m-CEPs was not studied in this survey and it therefore requires further research.

The number of device failures and discomfort problems was relatively high. M-CEPs used in Finland are made of silicone, which has been reported to sometimes cause irritation in the ear canal[10] similar to that caused by foam tips.[16] In the future, it might be useful to study and test new m-CEP materials in order to reduce irritation. Extended sortie durations are also likely to increase the number of discomfort complaints. The usage of m-CEPs would probably increase with improvements in custom fitting of the device and readjusting the fitting of the helmet, which, according to our experience, is often forgotten.

External ear canal barotrauma is a rare complication resulting from m-CEP use. Our survey identified two cases. One was caused by a vent malfunction and the other due to the immersion suit hood blocking the ear. Even though the problem is rare, it emphasizes the need of a well-functioning vent in the m-CEP, especially during sorties that include rapid altitude changes.

Hyperacusis was reported surprisingly commonly in the study population (8%). High aerodynamic noise exposure at high air speed may be one factor causing hyperacusis. More studies on hyperacusis and related risk factors should be carried out in the future.

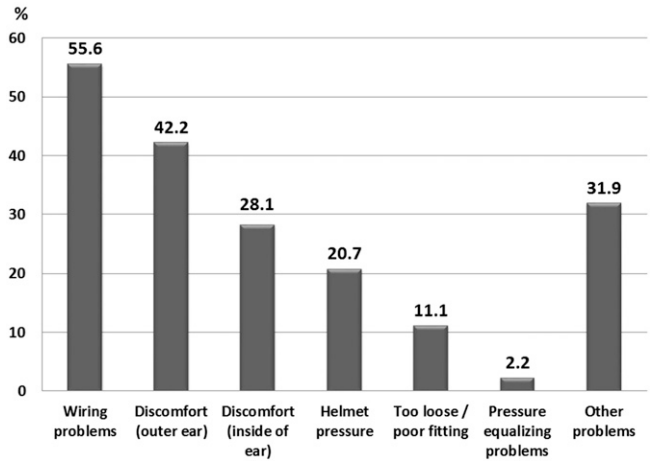

Fig. 3. Most common problems associated with m-CEPs (question 21). Percent of pilots who had used or tried m-CEPs and reported each issue, $N = 135$. One pilot was able to pick several options.

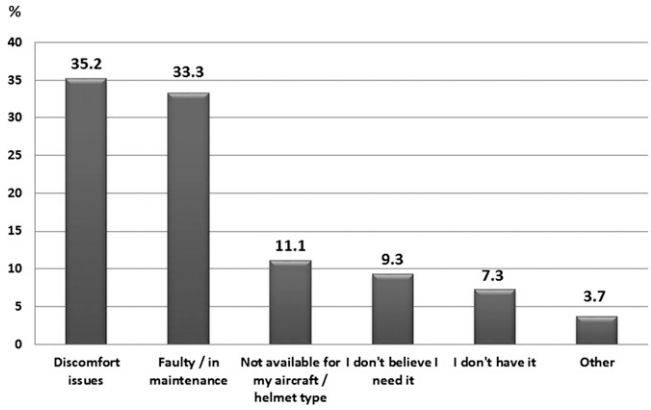

Fig. 4. Reasons for not currently using m-CEPs (question 18), $N = 55$.

Limitations of this study are that it assessed the experiences of pilots using m-CEPs subjectively. Only one m-CEP type was available at the time of this study. Also, other hearing protection systems, e.g., flight helmets with ANR, have been shown to be functional in previous literature, but they could not be studied because they were not in use for the subjects at the time of this study. The response percent (59%) of the study can be considered adequate, although the helicopter pilot subgroup consisted of only 19 pilots. It is probable that pilots who had no experience of m-CEPs or had nothing negative to say about the device did not return the questionnaire. Furthermore, the study was an anonymous survey, so the audiometric results of the pilots, among other factors, could not be correlated with the answers. Knowing this fact, we still chose anonymity in order to encourage pilots to report all issues they had encountered. Question 17 (how often do you use hearing protection when working in a noisy environment?) was excluded because the results showed that the question was not clear enough and had been interpreted differently. Recall bias might have had an effect on certain questions; e.g., some minor incidents may have been forgotten and not reported.

In the Finnish Air Force there have been three midair collisions over the past 15 yr. These have resulted in one fatality and, in these accidents, poor or inadequate radio communication has been at least a partly contributing factor.[18] These accidents underline the importance of understanding pitfalls in radio communication and of improving tools to enable efficient communication. Compared to our previous survey,[8] the amount of in-flight communication problems has remained the same at 14%. During air combat missions, the high cognitive load to which the pilot is subjected during the most intense mission phases has been shown to cause changes in radio speech,[5] adding a further challenge to radio communication. However, according to the current survey, pilots find the m-CEP a tool they can recommend and that increases communication intelligibility in their demanding working environment.

In conclusion, 85% of the pilots who have used or tried m-CEPs reported improved hearing with m-CEPs in an operational environment, and 93% of the subjects recommended

m-CEPs for their fellow pilots. Technical issues and discomfort remain a problem with m-CEPs.

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