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Speech Intelligibility in Rooms with and without an Induction Loop for Hearing Aid Users

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The paper presents the results of sentence and logatome speech intelligibility measured in rooms with induction loop for hearing aid users. Two rooms with different acoustic parameters were chosen. Twenty two subjects with mild, moderate and severe hearing impairment using hearing aids took part in the experiment. The intelligibility tests composed of sentences or logatomes were presented to the subjects at fixed measurement points of an enclosure. It was shown that a sentence test is more useful tool for speech intelligibility measurements in a room than logatome test. It was also shown that induction loop is very efficient system at improving speech intelligibility. Additionally, the questionnaire data showed that induction loop, apart from improving speech intelligibility, increased a subject's general satisfaction with speech perception.

Keywords: speech intelligibility, induction loop, hearing impairment, speech enhancement.
PACS: *43.71.-k, 43.71.+m, *43.72.-p, 43.72.+q; *43.66.-x, 43.66.+y; *43.55.-n, 43.55.+p.

1. Introduction

It is generally known that normal-hearing and hearing-impaired people have various degree of difficulties in understanding speech in adverse acoustic conditions. Such difficulties often occur in public places which are characterized by high levels of noise or a long reverberation time (RT). The Speech Transmission Index (STI) (Houtgast *et al.*, 1980; Steeneken, Houtgast, 1980) is often used to evaluate the effects of reverberation and noise on speech intelligibility for normal-hearing and hearing-impaired subjects (Brachmański, 2004; 2008; George *et al.*, 2010; Helfer, Wilber, 1990; Nabelek, Mason, 1981; Plomp, Duquesnoy, 1980). It was shown that the STI was a convenient measure to evaluate speech reception in noise or reverberant conditions both for normal-hearing and hearing-impaired subjects (George *et al.*, 2010). Quantitative evaluation of the effect of the adverse acoustic conditions on the speech intelligibility data requires choosing the appropriate intelligibility test. Many different speech intelligibility tests such as one-syllable words rhyme tests, words, logatomes or numbers have been introduced in the last decades. Most of these tests, however, do not reflect a real communication process in which the basic units are sentences. It appears that the sentence tests seem to be very useful to measure speech intelligibility in adverse acoustic conditions (Ozimek *et al.*, 2009a; 2009b; Plomp, Mimpen, 1979). The important advantage is that the context of the sentences, particularly when they are presented against noise, reflects a real communication process. Thus, the intelligibility study based on the sentence test should give the most adequate results, which are related to the real problems of the hearing impaired listeners who are forced to use different assistance tools to improve their intelligibility. However, on the other hand, the same context can make the sentence test useless in some situations in which the intelligibility score reaches 100%. In such situation the only solution is to use the test that is free of context like logatomes or syllables. Nevertheless, one must keep in mind that this kind of test is based more on recognition of the phonemes than on communication.

The second problem is how to improve speech intelligibility in an adverse acoustic enclosure, particularly for people with hearing impairment. Certain solution can be found in application of an induction loop system (Curtis Tannahill, 1983; Hinman *et al.*, 2003; Noe *et al.*, 1997; Rodriguez *et al.*, 1993; Sandrock, Schum, 2007; Sung, Hodgson, 1971; Van Tasell, Landin, 1980; Vargo *et al.*, 1970). In such system, the cable, properly distributed in the room, creating a closed loop, is connected to the loop amplifier output. An alternating current flowing through a conductor (loop wire) produces an alternating magnetic field. When there is a person inside the loop using a hearing aid equipped with a coil, an alternating voltage is formed due to the electromagnetic induction in the coil, corresponding to the signal from the sound source. The signal from the coil is processed in a similar way to the signal from the microphone of hearing aids; thus, an almost perfect match of the signal to the hearing loss is guaranteed as the frequency responses of the coil and the hearing aid microphone are almost the same (Ross, 2006). In this way adverse influence of the acoustical environment is eliminated.

A significant advantage of loops over FM (radio frequency) or IR (infrared) is that users do not need to use additional receivers, just their own hearing aid, because the hearing aid is fully equipped with a telecoil (which is the name of the feature based on the induction coil and is a standard component of currently manufactured hearing aids). More and more hearing aid (and cochlear implant) users can take advantage of induction loops with no additional costs. Furthermore, as telecoils are commonplace, there is a strong need to install facilities in public areas which help people with speech comprehension.

The aim of the present study is to measure speech intelligibility based on the sentence and logatome tests, for hearing aid users, in two chosen enclosures equipped with induction loop systems (Sec. 4). Apart from intelligibility measurements, speech communication assessments, using a questionnaire based on a modified Abbreviated Profile for Hearing Aid Benefit (APHAB), were also performed (Sec. 5).

2. Enclosures

The speech intelligibility measurements were conducted in the following enclosures:

- The meeting room (MR) of the Polish Association of the Deaf (PZG) – 48 m^2, with a height of 4 m, many absorbing and scattering elements, and a RT of about 0.8 s. In the case of the ‘no loop’ condition, the sound source used in the room was a Pioneer amplifier and a Tonsil Altus loudspeaker. Figure 1 shows a schematic diagram of the enclosure with the marked measurement points (1–6).
- A church (CH) – smooth walls, covered with plaster, the floor covered with marble. The RT of about 5 s. The sound system installed in the church is specially designed and characterized by high quality. Figure 2 shows the schematic view of the enclosure with the distribution of measurement points (1–8).

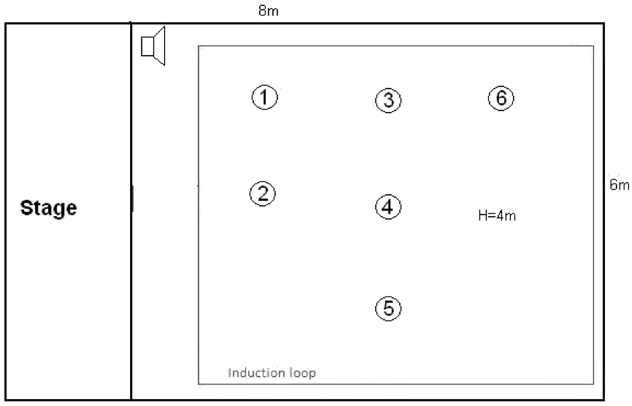

Fig. 1. Schematic view of the room MR, the location of the sound system and measuring points (1–6) are also depicted.

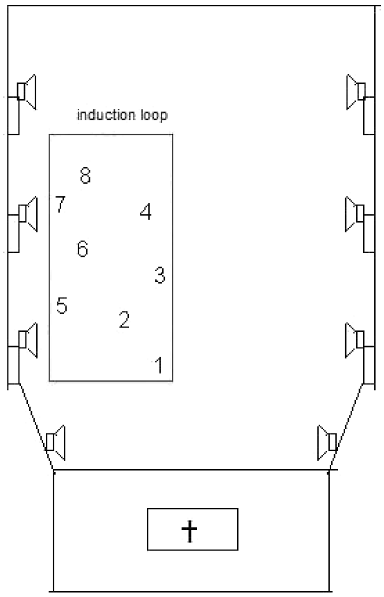

Fig. 2. Schematic view of the church (CH), the location of the sound system and measuring points (1–8) are also depicted.

3. Subjects

Twenty two hearing-impaired subjects took part in the experiment. The subjects were users of hearing aids of different types. Each of them had only one hearing aid. Moreover, all of them underwent audiometric examination for both ears. They were divided into five groups depending on the degree of their hearing losses, which were as follows: mild (20–40 dB HL), moderate (40–55 dB HL), moderately severe (55–70 dB HL), profound (90–120 dB HL) and one ear deafness (in this case in each enclosure the subject had moderate hearing loss in the opposite ear). When a subject had moderate hearing loss in one ear and severe hearing loss in the opposite one, he/she was included in the moderately severe group. The results of speech intelligibility were analyzed separately for the above-mentioned five groups. Figures 3 and 4 show the au-

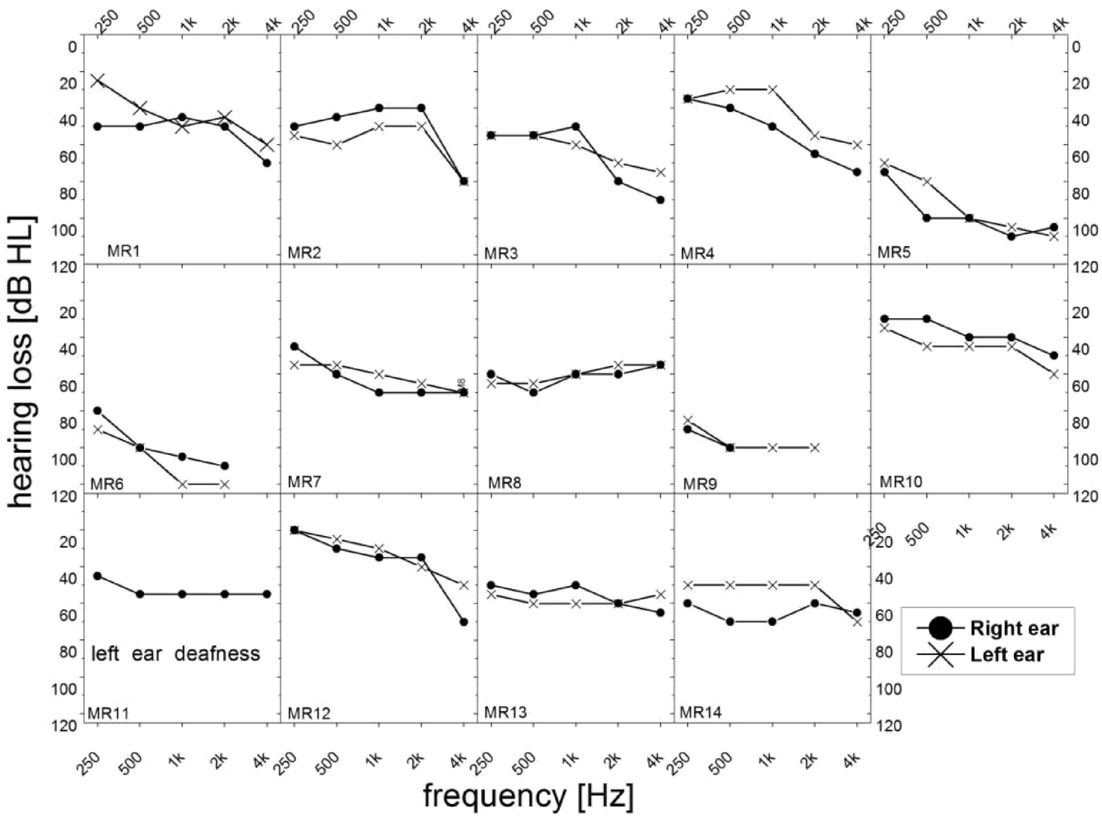

Fig. 3. Audiograms of the hearing-impaired subjects who took part in speech intelligibility measurements in room MR.

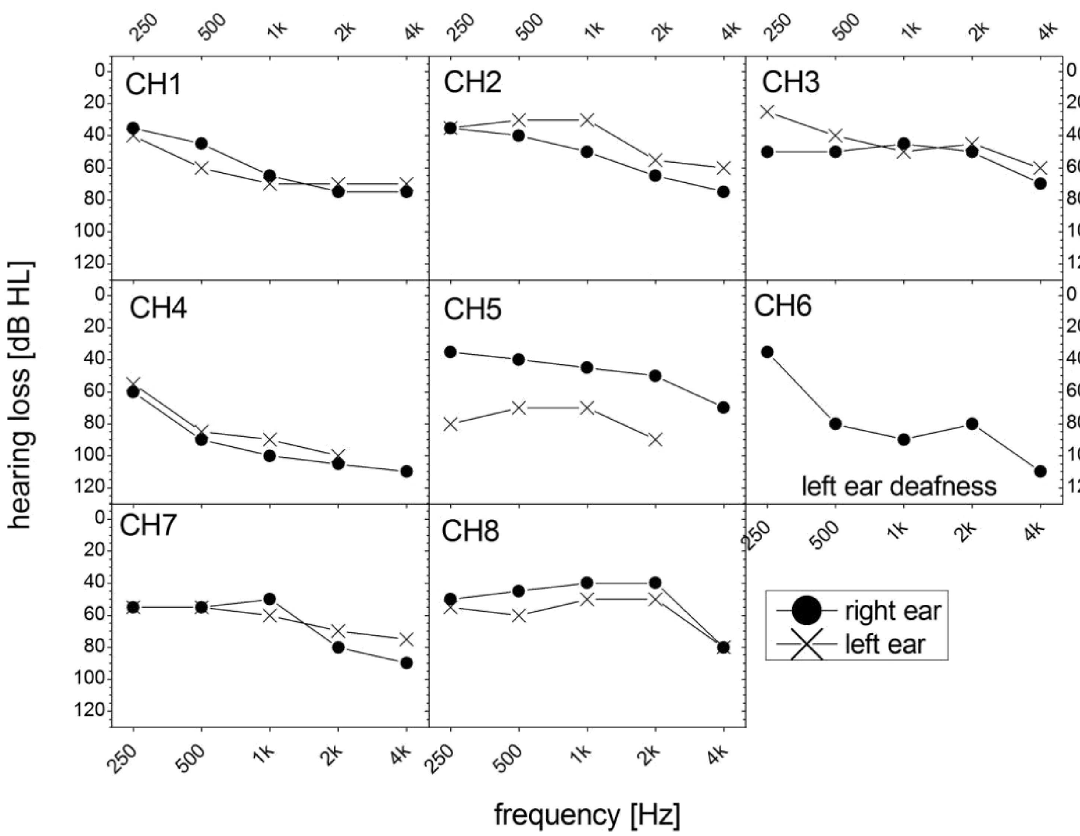

Fig. 4. Audiograms of the hearing-impaired subjects who took part in speech intelligibility measurements in room CH.

diograms of hearing-impaired subjects involved in the study. The reference group comprised 10 persons with normal-hearing.

4. Speech intelligibility measurements

4.1. Methods

The intelligibility tests, composed of sentences or logatomes, were presented to the subjects at fixed measurement points selected in the enclosures. A listening session, at a fixed measurement point, consisted of hearing the test with the induction loop system switched on and off. The hearing-impaired subjects listened to the tests using their own hearing aids. The induction loops with the amplifiers UniVox PLS-100 were installed in the enclosures. The speech signals were generated using an audio sound system or induction loop amplifier connected to a standard PC. The sound system was an integral part of the enclosure. The induction loop system was calibrated according to the IEC 60118-4:2006 norm.

The Polish sentence test (see (Ozimek *et al.*, 2009c) for details) and the traditional logatome test (Brachmanski, Staroniewicz, 1999) were used to determine speech intelligibility in each measurement points of the tested enclosures. The sentence test consisting of different lists of 13 elements each and logatome test with different lists of 50 elements each were used. The subjects were asked to write down all the speech elements (sentences or logatomes) they heard on a specially prepared form. Each subject carried out the listening session at five measurement points in the enclosure. The hearing impairment of the subjects was divided into five groups, namely: mild, moderate, moderately severe, moderate/one ear deafness, profound. The results were analyzed separately in each of these groups. Since results for different measurement points show no statistical difference [$F = 0.21$, $p = 0.53$], they were averaged across measurement points.

4.2. Results and discussion

A juxtaposition of the obtained results is shown in Fig. 5. Speech intelligibility vs. degree of hearing loss for both enclosures and for sentence and logatome tests is depicted there. Empty circles show the results related to without the loop condition (the signal was

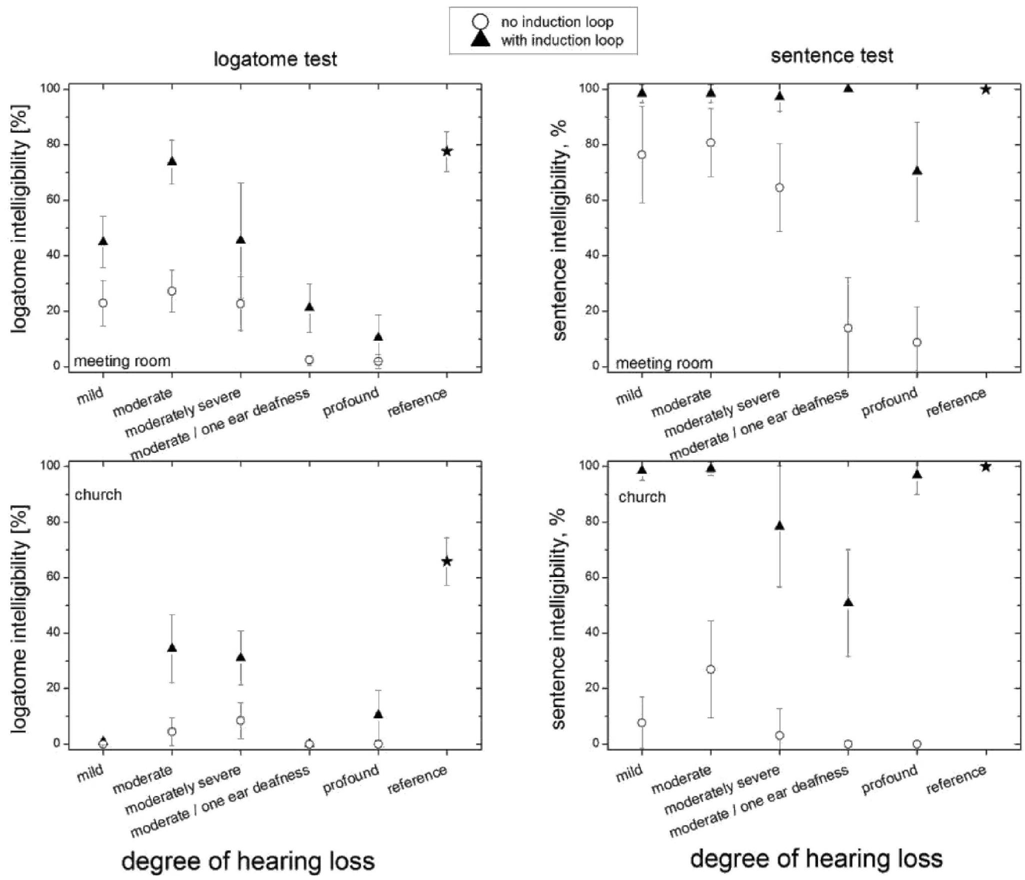

Fig. 5. Speech intelligibility as a function of a degree of hearing loss. The upper panels show the averaged (across measurement points) values obtained in the meeting room while the lower panels show the same results for the church. The left panels show logatome intelligibility, while right panels show sentence intelligibility. A reference value for normal-hearing subjects is given by asterisks.

generated via the sound system installed in the room and received by the subjects via their own hearing aid), whereas filled triangles show the results with the induction loop switched on (the telecoil option was switched on in the hearing aids). The asterisk shows the averaged intelligibility for the reference group (normal-hearing subjects). The upper panels show the results obtained in the meeting room (MR), while the lower panels show the results for the church (CH). The left panels show the logatome intelligibility, while the right panels show sentence intelligibility.

Generally, it may be stated that the results for both sentence and logatome intelligibility indicate that induction loops significantly improve speech intelligibility in both enclosures. However, for some subjects the improvement for the logatome test was not noticed for induction loops (see bottom left panel of Fig. 5). This is because those subjects did not follow the listening task. Despite the fact that they took part in a training session and they were clearly instructed how to fulfill the task, they tried to get the semantic meaning of the logatomes, resulting in writing down some words which sounded similar to particular logatomes, instead of the logatomes themselves. This fact supports the statement that the sentence test, which is more natural in perception and reflects the everyday problems with communication of hearing impaired people, is more adequate in such kind of research where psychological effects play a very important role. Furthermore, the data in Fig. 5 clearly demonstrates that sentence intelligibility is generally higher than logatome intelligibility. This is mainly due to the fact that sentences have contexts which constitute clues in everyday conversation.

The obtained results were subjected to a within-subject analysis of variance (ANOVA) with three factors: type of intelligibility test (sentence or logatome), type of listening (no induction loop and with induction loop) and degree of hearing loss. All the factors were proven to be very statistically significant in both enclosures: (1) the intelligibility test: $[F = 689; p < 0.001]$ for the meeting room and $[F = 242; p < 0.001]$ for the church; (2) the use of induction loop $[F = 416; p < 0.001]$ for the meeting room and $[F = 366; p < 0.001]$ for the church; and (3) degree of hearing loss $[F = 133; p < 0.001]$ for the meeting room and $[F = 25; p < 0.001]$ for the church. Moreover, the interactions between those factors are also significantly dependent: (1) degree of hearing loss ∗ type of intelligibility test $[F = 6; p < 0.001]$ for the meeting room and $[F = 4; p = 0.01]$ for the church; (2) degree of hearing loss ∗ the use of induction loop $[F = 7; p < 0.001]$ for the meeting room and $[F = 6; p < 0.001]$ for the church; (3) type of intelligibility test ∗ the use of induction loop $[F = 37; p < 0.001]$ for the meeting room and $[F = 174; p < 0.001]$ for the church. The interaction between all the factors was also proven to be statistically significant: $[F = 25; p < 0.001]$ for the meeting room and $[F = 4; p < 0.01]$ for the church. Generally, one can say that the intelligibility difference between the 'no induction loop' case and 'with induction loop' case depends not only on the hearing loss but also on the type of test used. Thus, one must be very careful while choosing the type of test. The present study indicates that the sentence test is much more adequate since it provides not only more unequivocal data but reflects natural communication processes.

To investigate the effect of RT of the room on speech intelligibility for cases without and with induction loops, the results were averaged across the tested groups. The obtained data for two values of RT is shown in Fig. 6.

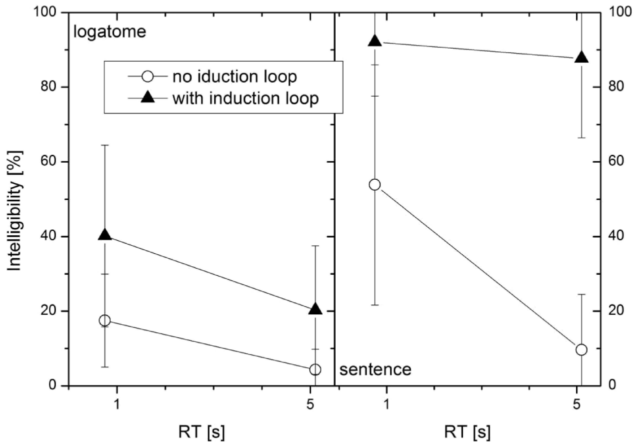

Fig. 6. Logatome and sentence speech intelligibility vs. reverberation time (RT) averaged across all groups of the subjects.

The results show that in the cases when the induction loop was switched off (the speech tests were generated from the sound amplification system), speech intelligibility both for sentences and logatomes was very poor in rooms with a long RT, as was to be expected. Moreover, ANOVA showed statistical difference between these two conditions with different RT $[F = 25; p < 0.01]$. However, when listening with induction loops took place, the speech intelligibility was significantly improved, particularly for the sentence test and was independent from RT $[F = 0.12; p = 0.68]$. In subjects with mild losses, it reached about 95% for the sentence test, while for those with a deeper impairment the benefit from the use of induction loops was smaller but still significant. The results obtained for the logatome and sentence tests in two tested rooms (with RTs of 1 and 5 s), when induction loops were applied, differed only slightly because the use of loops "bypasses" the influence of room parameters on the signal transmission. A slight difference seen between those results might be caused by the fact that the subjects listened to the speech signal with both ears, namely one with a telecoil and the other without any aid. In this case the reverberant speech signal perceived by from the unaided ear might interact, on the higher level of the hearing pathway, with the signal from the hearing aid. Generally, one can conclude that when an induction loop is installed in a room, even adverse reverberant conditions do not affect sentence speech intelligibility, which is usually very high (about 95% in this study).

Moreover, analyzing Figs. 5 and 6, it may be stated that the sentence test seems to differentiate more the tested conditions. Namely, the difference between 'no induction loop' and 'with induction loop' values are greater for sentence test, which is very important in many cases in which the difference between results for various conditions might be more equivocal.

5. Subjective assessment of speech understanding and communication using query

Apart from direct measurements of speech intelligibility, data gathered by means of a questionnaire based on a modified Abbreviated Profile for Hearing Aid Benefit (APHAB) (Cox, Alexander, 1995; Cox, Gilmore, 1990) were calculated. The hearing aid users who participated in this research were asked to fill in the appropriate questionnaires. The original APHAB questionnaire was adapted to measure the benefit from using an induction loop. Questions focused on speech communication. A standardized 7-point answer scale was used: A – always (99%), B – almost always (87%), C – generally (75%), D – half-the-time (50%), E – occasionally (25%), F – seldom (12%), G – never (1%). All ten questions are listed below:

1. When I am watching TV in a quiet room, it's hard for me to understand what is being said.
2. I miss a lot of information when I'm watching TV.
3. It's hard for me to understand what is being said in a reverberant room.
4. I can hardly follow the words of a sermon when listening to a religious service.
5. The speech in a room is distorted.
6. The words I hear in a room are "blended".
7. The speech in a room is not loud enough.
8. I have problems with speech understanding in a room.
9. I have problems with speech understanding in a noisy room.
10. When I am talking with someone through a window (e.g. at the railway station cashbox), I hardly understand the words.

In Table 1 the mean values for all subjects and for particular questions are presented.

Taking into account the answers gathered in Table 1, a global assessment of induction loops can be calculated as a mean value over all questions (Fig. 7).

Table 1. The averaged results of the subjective assessment of the effect of induction loops, according to 10 questions on a questionnaire. The last column presents the subjective benefit from the induction loop.

Question	Without induction loop [%±SD]	With induction loop [%±SD]	Benefit (difference between score without induction loop and with induction loop) (percentage points)
1	90.83±20	24.67±19.62	**66.17**
2	86.83±20.44	16.67± 9.97	**70.17**
3	91.00±12.39	10.83±11.77	**80.17**
4	86.83±20.44	18.67±17.13	**68.17**
5	70.33±36.32	18.67±17.13	**51.67**
6	78.67±28.80	12.67±10.74	**66.00**
7	43.67±22.15	10.50± 8.92	**33.17**
8	78.67±24.07	24.67±19.62	**54.00**
9	93.00±10.04	16.83±18.52	**76.17**
10	74.50±30.21	18.67±17.13	**55.83**

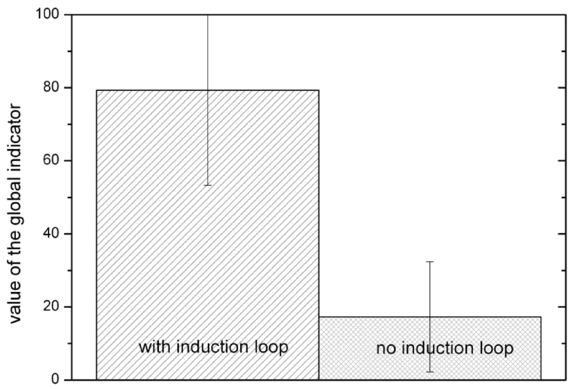

Fig. 7. Global indicator representing satisfaction of the hearing aid users in the speech intelligibility task over all questions and all subjects.

As can be seen, all the answers show that induction loops are very effective at improving speech intelligibility (speech intelligibility tests) and subjects' satisfaction (questionnaires). The percentage of problems with speech understanding reported by subjects was significantly lowered by the use of induction loops in all conditions. A global reduction of problems (benefit from the induction loops) is more than 62 percentage points, which indicates the high effectiveness of this system. Moreover, the data shows that the use of induction loops, in general, significantly lowers the standard deviation across subjects and across global value. This means that induction loops are efficient for different levels of hearing loss.

To conclude, it may be stated that both speech intelligibility measurements and questionnaires show that induction loops are very efficient; thus, it is recommended that this system should be used more often, especially in public areas characterized by a long RT and a relatively high noise level.

6. Conclusions

The following conclusions can be drawn from the present study:

- the use of induction loop significantly increases speech intelligibility in both investigated enclosures,
- the adverse influence of reverberation on speech intelligibility in hearing-impaired subjects is very strong, however, the use of induction loops reduces this effect significantly,
- the sentence test appeared to be adequate to measure speech intelligibility in most of the cases. Moreover, it provided higher differentiation between results for different conditions. Nevertheless, one must keep in mind that due to context in some situations the sentence test might not be applicable, especially in those cases in which the intelligibility is very high. In such situations one must resign from better representation of communication process (that includes context) in favour of more difficult test based on recognition (logatomes or syllables).
- the questionnaire data suggests that induction loops are very effective for improving both speech intelligibility and a subject's general satisfaction with speech perception.

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