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Quantifying the bystander-effect of 2.5G mobile telephones on the speech perception of digital hearing aid users

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Abstract. *Quantifying the bystander-effect of 2.5G mobile telephones on the speech perception of digital hearing aid users. Objective*: To quantify the bystander-effect of 2.5G mobile telephones (2.5G-MTs) on the speech perception of digital hearing-aid (dHA) users. Differences in the susceptibility of behind-the-ear (BTE) compared to in-to-the-ear (ITE) dHAs were also assessed.

Materials/Methods: Prospective-comparative study conducted at a tertiary referral centre (ENT Department) and a HA-fitting laboratory. Key-word recognition scores from open-sentence lists were calculated. Power-analysis determined that a minimum of 60 subjects with SNHL (30 in each group), using either BTE or ITE dHAs, were required for reliable study outcomes. Sixty-four adults were tested with a functioning 2.5G-MT at almost physical contact with their ear; thirty subjects used BTE and 34 ITE dHAs.

Main outcome measures: Aided word recognition score differences between studied groups and within each group, while a 2.5G-MT was activated. Cut-off inclusion criterion regarding baseline aided word recognition score was 75%.

Results: Baseline aided word recognition scores for ITE dHAs were better compared to BTE ones ($p < 0.01$). Following the 2.5G-MT activation, this difference disappeared. No statistically significant difference in word recognition was observed between the examined groups, or within the BTE group, from the bystander-effect of the 2.5G-MT. ITE dHAs proved more susceptible to electromagnetic interference ($p < 0.05$).

Conclusion: The bystander-effect of 2.5G-MTs on the speech perception of dHA users is either minimal, or not significant. The observed compatibility has a positive impact on the lives of millions of people worldwide. The long-standing theory of more interference in BTE compared to ITE HAs is not confirmed by the results of the present study.

EBM level of evidence: 2c.

Introduction

Sensorineural hearing loss (SNHL) is an insidious and potentially devastating chronic condition, which may have a serious impact on both physical and social function of the affected individuals. The treatment of SNHL and the restoration of normal hearing have been, thus, intensively pursued, however, wide-spread medical or surgical interventions for listeners with SNHL cannot be currently applied in clinical practice. Therefore, the provision of amplification and the associated rehabilitation remain the only effective means for managing SNHL.[1-3]

On the other hand, a main feature of modern societies is the proliferation of communication systems and devices, by which information can be rapidly delivered, displayed and explored. Mobile telephones have been one of the major constituents for our increasing communication capabilities and have essentially become a requirement for every citizen that wants to fully participate in the Western civilization. However, the introduction of digital wireless technologies has set potential new barriers to the accessibility of hard of hearing people to the available information, because of the possible audible electromagnetic interference (EMI) which is generated by their combined use.[4,5]

EMI between mobile phones and digital hearing aids is caused by the special nature of radio signals, due to the principle of time-division multiple access used in GSM networks. The effect of EMI, in principle, would be degradation in the performance of the hearing aids, as a result of the electromagnetic disturbance caused by the operating cellular phone.[6] This degradation may preclude the hearing aid wearer from using new digital communication technologies, and may also produce annoying or even harmful sound pressure levels (SPL).[7]

Whilst direct EMI from a functioning cell phone in hearing aid users has now become well acknowledged,[8-10] it has also been reported that nearly 50% of the respondents in a study funded by the British Hearing Concern Organization, which represented a wide cross-section of the hearing aid wearing population in Great Britain, could hear interference noises from other people's mobile phones (indirect or bystander effect), even at distances of more than two meters in some circumstances (Radio Frequency Hearing Impaired Committee-Executive Summary).

The aim of the present paper is to investigate the potential bystander effect of advanced second generation mobile telephones (2.5G) on the speech perception of digital hearing aid users. Potential differences in the susceptibility of behind-the-ear (BTE) compared to in-the-ear (ITE) hearing aids were also assessed.

Materials and methods

Sixty-four adults with SNHL who were using digital hearing aids were recruited for participation in the study; thirty-eight of them were males and 26 females.

The hearing impairment of each participant was calculated, according to the general guidelines of the American Academy of Otolaryngology, modified to include the frequency of 4000 Hz, instead of 3000 Hz, as more reflective of the condition of the speech frequencies. In brief, the average air-conduction hearing threshold at the frequencies of 500, 1000, 2000, and 4000 Hz in each ear of each tested participant was initially calculated. Twenty-five (25) dBs were then extracted (less threshold fence), and the remaining value was multiplied by 1.5 to equal the percentage of monaural impairment. The percentage of impairment of the better hearing ear of a given participant was then multiplied by 5. The percentage of impairment of the worse hearing ear was added, and the sub-total was divided by 6. The result was the percentage of binaural hearing impairment. Unilateral hearing losses were excluded from the study.

The participants were divided into two groups, on the basis of the type of the hearing aid they were wearing; 30 subjects in the BTE group and 34 in the ITE group. Each participant had worn his/her digital hearing aid for a minimum of six weeks, before being tested.

The digital hearing aids which were used in the study belonged to the same manufacturer (Siemens™). The ITE group included participants that were using cosmea top (Siemens™ CT) hearing devices, or smaller in-the-canal hearing aids (Siemens™ cosmea small-CS), or even completely-in-the-canal hearing devices (Siemens™ CIC). However, the characterization of ITE hearing aids initially corresponded to the size and dimensions of the CT hearing devices. The more miniaturised CS and CIC models were developed more recently; however, the current audiologic practice considers all the above mentioned hearing aids as ITE. This was also adopted in our study without jeopardising the homogeneity of the ITE sample, as seen in Table 1.

Each of the participants was examined separately by the same certified audiologist in a quiet examination room (ISO 8253-2). The participant was seated in the centre of the room wearing his/her hearing aid and was subjected to a fixed speech intensity of 65 dB SPL, coming out of a Dunlop loudspeaker at a distance of 1.25 m at 0° azimuth. This intensity, which represents the usual level of normal voice,[11,12] had been measured by a portable sound-level meter at the centre of the subject's head, with the subject removed from the sound field. The audio system also included a computer DVD/CD-ROM (PHILIPS™ DVD 8631) working on a SOUNDMAX Integrated™ Digital Audio sound card. In case that the participant wore two hearing aids only the one under examination was activated. The instruments which were used during the study were the same for all tests.

The methodology of the study was based on speech perception using the Bamford-Kowal-Bench (BKB) sentence lists, which are considered as the standard open sentence test in the United Kingdom. The lists were appropriately translated and adapted to meet the requirements of the Greek language. Five different lists of equal difficulty, each of them comprising of 20 sentences, were randomized. Subject performance was assessed as the number of key-words (out of a total of 50 for each list) that were correctly identified, and was then expressed as % percentage by doubling the total score of the correctly identified key-words. Following the presentation of a sentence to the listener, the participant was instructed to repeat it during a fixed pause of 20 seconds until the next sentence would begin (verification time). All lists were presented by the same trained male speaker and special care was taken during CD recording to ensure that into-

Table 1

ANOVA data verifying sample homogeneity in ITE hearing aid wearers

Sample parameters		ITE sub-type		
		CIC	CS	CT
Hearing impairment (%)	$\bar{x}$	48.56	48.37	51.04
	SD	11.13	13.87	6.48
	F	1.011		
	P	0.447		
Age	$\bar{x}$	61.55	76.60	67.78
	SD	17.08	6.77	14.16
	F	2.327		
	P	0.225		
Baseline word recognition score (%)	$\bar{x}$	96.90	97.60	96.67
	SD	2.63	2.61	3.32
	F	0.755		
	P	0.479		

Note: $\bar{x}$: mean value
SD: standard deviation
F: F-test
P: observed statistical probability.

nation contours of the spoken material and duration of voicing were similar for all sentences,[13] in order to avoid cues not directly associated to the intelligibility of each key-word.

Only patients with baseline aided word recognition scores of 75% and higher were included in the study, as less discrimination puts into question the effectiveness of hearing amplification, and/or the success of hearing aid fitting. The patients who met the cut-off criterion were then asked to repeat the testing (hearing a different list, but following the same methodology) with a functioning 2.5G mobile phone at almost physical contact with their ear and again the total score of the correctly identified key-words (and the respected percentage) was noted. The phone was firmly held by a research assistant standing at the back of the patient and at no time was in contact with the patient's hearing aid. In cases of BTE hearing aids the phone was put in the upper part of the pinna, whereas in ITE hearing aids it was put slightly above the ear lobe, but not directly between the hearing aid and the loudspeaker, in order to avoid the presence of an "acoustic shadow".

The mobile phone utilised for this study was a Motorola V3i (Samsung Co), which transmits and receives radio signals in the region of 900 MHz using the GSM system. Overall testing time was approximately 30 min.

A power analysis revealed that a minimum of 60 subjects (30 in each group) were needed to find, at the $p = 0.05$ level of statistical significance, with 90% certainty, a difference of at least 3% in word discrimination between the two groups. Paired student's t-test was performed to assess the measured differences in speech perception within each group after the activation of the cellular phone. Independent t-test was used to compare the difference in speech perception between the examined groups after the activation of the mobile telephone. The SPSS 16.0 statistical package was used to compare variance within the ITE group (analysis of variance-ANOVA). Statistical importance was accepted at a level of 0.05.

Ethical considerations

The research protocol was submitted and received ethical approval by the Ethics Committee of the University of Athens, prior to commencing measurements in any of the participants. Participants were asked to sign a consent form before being enrolled in the study.

Results

General demographic data of both study groups are demonstrated in the fist two columns of Table 2. As expected, the hearing impairment of ITE wearers was less severe compared to the BTE group ($p < 0.01$). The respective mean age differences were also statistically significant, with ITE wearers being younger than their BTE counterparts ($p < 0.05$).

The initial aided word recognition scores also showed a baseline difference between the two examined categories of hearing aids. The ITE group scored better than the BTE under aided conditions and this difference was found statistically significant ($p < 0.01$) (Table 2-column 3).

In the BTE group, following the activation of the mobile phone, a minor decline in the mean aided word recognition scores was observed. This did not prove statistically significant.

Table 2

Comparison of basic parameters between BTE and ITE hearing aid wearers

Hearing aid type	Hearing impairment (%)			Age			Baseline word recognition score (%)			Interfered word recognition score (%)		
	$\bar{x}$	SD	P	$\bar{x}$	SD	P	$\bar{x}$	SD	P	$\bar{x}$	SD	P
BTE	59.58	17.60	<0.01	73.23	11.27	<0.05	94.8	3.62	<0.01	94.33	3.75	<0.1
ITE	48.73	10.29		65.41	15.86		96.94	2.75		95.65	4.25	

Note: $\bar{x}$: mean value
SD: standard deviation
P: observed statistical probability.

The activation of the mobile phone in the ITE group resulted in a more noticeable decrease in the mean aided word recognition scores (1.29%). The measured difference was proven statistically significant ($p < 0.05$).

A comparison of the measured differences in aided word recognition scores between BTE and ITE hearing aids following the activation of the cellular phone found no statistically significant difference at the level of 0.05. However, the mean aided word recognition scores after the activation of the mobile phone were no longer statistically significant between the two hearing aid categories ($p < 0.1$) (Table 2-column 4).

Discussion

Epidemiologic and statistical data concerning hearing impairment, though generally estimate the occurrence of a dysfunction in the organ-level, often fail to recognize the implications of that impairment in people's everyday life, or its emotional and social consequences. The effect is greater when we take into consideration that only 23% of adults with an ascertained hearing impairment actually use hearing aids.[14,15] Stigmatization, financial constraints and the subjective perception of uniqueness in their hearing loss pose as the main barriers for hearing aid adoption amongst the hearing impaired and a considerable number of hearing aid users finally stop wearing them.[16] It is interesting to note that as much as 20% of people, who returned their hearing aids, were reportedly driven to do so by an inability to use them while talking on the telephone.[14]

The very high importance of mobile phones in modern society, in which no longer are they considered a luxury but an everyday necessity, may add a potential new barrier to hearing aid users. Moreover, the analog to digital shift that took place in the mid-90s with regard to mobile phone technology and was in a large part driven by the serious capacity limitations of analog networks[6] revealed an additional compatibility problem between cell phones and hearing aids, because of the audible EMI which is generated by their combined use.[4,5]

Acoustic interference occurs in hearing aids due to the pulsing pattern of the electromagnetic waves that are emitted by the mobile phone and typically originates in those parts of the circuits where the signal level is low and the gain is high, i.e. the microphone amplifier or the microphone itself.[12] The repetition frequency of EMI in GSM networks is 217 Hz,[6,12] thus falling (along with its harmonics) within the audible frequency range, and is perceived by the hearing aid user as a buzzing sound.[7,17] In addition to the perceived annoyance, EMI may lead to a decrease in hearing aid gain either by activating the automatic gain control, or because the hearing aid enters the saturation level.[6,7,17]

Indeed, in a study funded by the Hearing Concern Organization in Great Britain, more than 50% of hearing aid wearers had experienced a lot or some discomfort when trying to use a digital mobile phone (Radio Frequency Hearing Impaired Committee-Executive Summary). The perceived annoyance has also been associated with poor word and sentence recognition scores.[6,18] The baseline input-related noise in order for a hearing aid user to be able to communicate through a mobile phone has been estimated to 47dBSPL, while a substantial decline in speech recognition scores has been reported when the speech-to-noise ratio drops below 20-30dB SPL.[19] As a result, 60-80% of those who tried to use their hearing aid directly with a digital mobile phone have actually failed to do so.[12,19]

Evidence also suggested the experience of EMI from hearing aid wearers in the vicinity of other people using mobile phones.

Hence, nearly half of the respondents in the Hearing Concern Survey reported hearing interference noises from other people's cell phones, even at a distance of more than two meters (Radio Frequency Hearing Impaired Committee-Executive Summary). This finding was also confirmed by other studies, though reportedly affecting a smaller percentage of hearing aid users.[12,20]

However, these studies only reported the presence of a subjective annoyance from the existence of this bystander effect, whereas no quantification of its potential impact, in terms of word or sentence recognition scores, had been ever attempted. This was the aim of the present study.

Following a standard protocol, no statistically significant difference in speech perception was found in BTE hearing aid wearers after the activation of an advanced second generation mobile phone at close contact. ITE hearing devices, on the other hand, proved more susceptible to bystander electromagnetic interference, thus resulting in statistically significant decrease in speech perception. However, the clinical importance and the ensuing social impact of that decrease, in terms of a functional handicap of ITE hearing aid users, appear minimal.

These findings are considered very important as they confirm the communication compatibility between digital hearing aids and advanced technology mobile phones. The fact that a single model of 2.5G mobile phone was used in the present study needs to be taken into account, as also that this phone was not a newer 3G, or smartphone model. However, it should also be noted that the 2.5G mobile phones still represent the market leader of cellular phones, especially amongst more senior persons, due to their simpler user-phone interface, their lower retail price, and the reasonable additional utilities, which they can support.

BTE hearing aids are supposed to be more susceptible to EMI than ITE.[10] Although the evidence is very limited, the proposed reasons for the decreased EMI susceptibility of ITE devices included their confined circuitry in comparison with their BTE counterparts, which was considered less probable to serve as an antenna, along with their decreased output compared to BTE hearing aids, which presumably amplified the audible interference to a lesser degree. In addition the soft tissues of the ear were thought to attenuate the interfering electromagnetic signals and the positioning of their microphone prevented them from receiving background noise.[6]

However, the results of the present study suggest that the whole theory may not be applicable in modern devices. Even though the word recognition scores in ITE hearing aids were higher than the respective percentages in BTE devices, as expected from the level of hearing ($p < 0.01$), the decrease in word recognition was also greater. In other words the impact of the bystander effect on ITE hearing aids seemed greater than on BTE ones. Although one could argue that the difference between the two categories did not reach a level of statistical significance, a closer look at the data of Table 2 may suggest an additional interpretation. Hence, the mean word recognition scores after the activation of the mobile phone were no longer statistically significant between the two hearing aid categories; that means that the ITE hearing aids were indeed more susceptible to the bystander effect of the operating 2.5G mobile phone, to the extent that their decreased word recognition scores have resulted into similar speech perception in ITE and BTE wearers, despite their well-documented baseline differences.

As mentioned earlier, only patients with baseline aided word recognition scores of 75% and higher were included in the study as less discrimination would put into question the success of the respective hearing aid fitting. The participants in our study had in fact scored quite high, as far as key-word (or sentence) recognition was concerned, potentially raising the possibility of a ceiling effect in our measurements. Indeed, when many subjects in a study have scores on a variable at the upper limit of what the study instrument reports, data analysis is difficult because some actual variation in the data may not be reflected in the scores obtained from that instrument. A ceiling effect, however, is thought to occur when a high proportion of subjects in a study have maximum scores on the observed variable.[21] None of the participants in our study achieved maximum scores. Moreover, the appropriate number of participants to determine a difference of at least 3% in word discrimination was based on power analysis, thus ensuring that reliable comparisons between ITE and BTE hearing aids would be conducted.

Speech recognition assessment involves a dilemma because clinicians want a test that is short and reliable, but statistical principles dictate that a short test is probably unreliable.[22] Therefore, special attention was paid during the design of the research protocol to the collection and assessment of the data that were used in the evaluation of the potential bystander interaction between hearing aids and mobile phones. As the speech tests conducted comprised an important part of that assessment, only hearing aids less than five years of age (a generally recognized mean hearing aid lifetime[12,16]) were included in the study, thus excluding a potential bias with regard to the accuracy of the reported results. Attention was also drawn to the fact that when a hearing aid is situated in the near field of the phone antenna, it is very sensitive to the positioning of the telephone.[7,12] Therefore, the functioning mobile phone was firmly held by a research assistant and not by the patient him/herself, and at no time was in contact with the patient's hearing aid, in order to have reliable and repeatable data.

Furthermore, it has been well acknowledged that the extent of the benefit provided by a hearing aid does not appear to stabilize until about six weeks after fitting.[1] Therefore, all participants in our study had worn the hearing aids that were evaluated for at least this period of time. Moreover, care was taken during our measurements to avoid the potential impact of a sound deprivation effect on our results.[23,24] Auditory deprivation basically refers to a systemic decrease in speech processing ability over time, associated with a reduced availability of acoustic information.[1,25] As all participants were consistent hearing aid wearers, this well-documented entity was unlikely to have occurred in our study.

Conclusion

The ever-increasing use of electronics has created de facto systems that must operate acceptably. EMI between mobile phones and digital hearing aids is caused by the special nature of radio signals, due to the principle of time-division multiple access used in GSM networks and may result in a degradation in the performance of the hearing aids. However, the inability to communicate over the phone might impede the full participation of hearing impaired individuals in our information society and result in a diminished acceptance of hearing aids amongst them, with potentially devastating effects. The results of the present study suggest that the bystander effect of 2.5G mobile telephones on the speech perception of digital hearing aid users is minimal or of no concern for them. Thus, the compatibility of digital hearing aids and modern mobile phones found in the present study has a positive impact on the lives of millions of people worldwide. In addition, the long-standing theory of more interference in BTE in comparison with ITE hearing devices does not seem to be confirmed by the results of the present study. Overcoming the communication barriers created by the interaction between cellular phones and hearing aids is a case in point for modern societies, because, despite the state of rapid information flux in which they are obliged to function, it can help them remain truly inclusive.

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