Digital in-the-Ear Hearing Aids are Susceptible to Bystander Electromagnetic Interference from 2.5G Mobile Telephones

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Abstract: *Aim*: To quantify the bystander effect of advanced second generation mobile telephones (2.5G) on the speech perception of in-the-ear (ITE) digital hearing aid users.

Materials/Methods: Prospective study conducted at a tertiary referral centre (ENT Department) and a hearing aid-fitting laboratory. Thirty four adults with SNHL were included, and tested with a functioning 2.5G mobile telephone at almost physical contact with their ear. The cut-off inclusion criterion regarding the baseline aided word recognition score was 75%.

Results: The ITE group comprised 23 males and 11 females. The mean age was 65 years (age range 24 – 84), and the mean hearing loss in the aided ear 48.73dB. The mean baseline aided word recognition score of the examined ear was 96.94%, and declined to 95.65% following the activation of the mobile phone. The difference was statistically significant ($p< 0.05$).

Conclusion: There is statistically significant difference in the speech perception of ITE hearing aid users after the activation of a 2.5G mobile phone at close contact, due to the bystander electromagnetic interference. Although, the clinical importance and the ensuing social impact of the observed decline in speech perception appear minimal, it seems reasonable for designing efforts to focus on establishing better hearing immunity for ITE hearing aids.

Keywords: Mobile phones, hearing aids, interference, speech perception.

INTRODUCTION

Sensorineural hearing loss (SNHL) is a subtle and potentially destructive chronic condition, which may have a serious impact on both physical and social function of the affected individuals, though it is generally perceived as an inevitable consequence of normal aging. Hence, the importance of SNHL treatment is well acknowledged and the restoration of normal hearing has been intensively pursued. Although gene manipulation and stem cell therapy represent exciting new alternatives in SHNL treatment which can favourably modify the biology of hearing, they cannot be currently applied in clinical practice [1, 2]. Therefore, the provision of amplification and the associated rehabilitation remain the only effective means for treating SNHL [3-5]. Indeed, hearing aids were shown to significantly improve the quality of life of the hearing impaired individuals, by reducing the psychological, social and emotional effects of SNHL [6-8].

On the other hand an inherent characteristic of modern Western societies is the abundance of communication channels, by which information can be promptly searched, transferred and displayed [9]. Modern methods of mobile communication have been one of the major pillars of our increasing communication capabilities, and have essentially become a commonplace 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 hearing aid wearers to the available information, because of the audible electromagnetic interference (EMI) which is generated by their combined use [10, 11].

In principle, EMI refers to deterioration in hearing aid performance, due to the electromagnetic disturbance caused by an operating cellular phone [12]. The essence of the problem for hearing aid wearers is that such deterioration can make speech understanding difficult, thus discouraging them from using new digital communication technologies, and also produce annoying or even harmful sound pressure levels which may render the phone practically unusable [13, 14].

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While direct EMI from a functioning cell phone in hearing aid users is a focus of continuing research [15-17], 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, experienced interference from other people's mobile phones (indirect or bystander effect), even at distances of more than two meters in some circumstances [18].

The aim of the present paper is to investigate the potential bystander effect of advanced second generation mobile telephones (2.5G), which represent the market leader of cellular phones among persons who are more likely to be needing hearing amplification, on the speech perception of digital in-the-ear (ITE) hearing aid users.

MATERIALS & METHODS

A prospective study was conducted at a tertiary referral centre (ENT Department) and a hearing aid-fitting laboratory in 34 adult digital ITE hearing aid users. Inclusion criteria was the presence of bilateral SNHL necessitating the fitting of a hearing aid, a time period of at least 6 weeks, during which the participants in our study had worn the hearing aid(s) under evaluation, and a minimum baseline word recognition score of 75% (see also below). Unilateral hearing losses, children, conductive or mixed types of hearing losses, and other than air conduction hearing aids were excluded from the study.

The hearing impairment of each participant was calculated, according to the general guidelines of the American Academy of Otolaryngology [19], modified to include the frequency of 4000Hz, instead of 3000Hz, 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 4000Hz in each ear of each tested participant was initially calculated. Twenty-five 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.

The digital hearing aids which were used in the study belonged to the same manufacturer (Siemens™). Within the ITE group three hearing aid subcategories were recognized; participants were either using cosmea top (CT) hearing devices, or smaller in-the-canal hearing aids (cosmea small-CS), or even completely-in-the-canal hearing devises (CIC). It should be noted that although the characterization of

Table 1: ANOVA Data Verifying the Homogeneity of the ITE Group

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	2.4627		
	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.

ITE hearing aids initially corresponded to the size of the CT hearing devices, current audiologic trends allow us to consider also as ITE the later developed CS and CIC models, without jeopardising sample homogeneity, due to the common philosophy and technology which is incorporated in the design of all three types (inclusion of microphone-amplifier-receiver into the shell, taking advantage of the concha effect, etc.) (Table **1**).

Each of the participants was individually examined by the same certified audiologist in a quiet examination room (ISO 8253-2). The participant was seated in the centre of the room wearing an operating hearing aid, and was subjected to a set speech intensity of 65 dB SPL, coming from a Dunlop loudspeaker at a distance of 1.25 m at 0^{o} azimuth. This intensity, which represents the usual level of normal voice [20, 21], had been measured prior to the initiation of the test 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 the Bamford-Kowal-Bench (BKB) sentence lists, which are considered as the standard open sentence test in the United Kingdom [22]. The lists were appropriately translated and adapted to meet the requirements of the Greek language. Five different lists of equal difficulty, each of them including a scenario of 20 sentences, were used. Subject performance was assessed as the number of key-words (out of a total of 50 for each scenario) that were correctly identified, and was then expressed as a % 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 sec, until the next sentence would begin (verification time). All scenarios were presented by the same trained male speaker, and special care was taken during CD recording to ensure that intonation contours of the spoken material and duration of voicing were similar for all sentences, in order to avoid cues not directly associated to the intelligibility of each key-word.

The study only included patients with word recognition scores of 75% or higher, 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 scenario, but following the same methodology) with a functioning 2.5G mobile phone at very close proximity (almost physical contact) with their ear and again the total score of the correctly identified key-words (and the respective 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. Furthermore, it was also positioned slightly above the ear lobe, in order to avoid the presence of an "acoustic shadow".

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

The SPSS 16.0 statistical package was used to compare the variance within the ITE group (analysis of variance-ANOVA) (Table **1**). Paired student's t-test was performed to assess the measured differences in speech perception within the ITE group after the activation of the cellular phone. 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

There were 23 males and 11 females among the ITE digital hearing aid users. The mean age was 65 years (age range 24 – 84). The mean hearing loss in the aided ear was 48.73dB, and the mean binaural hearing loss 49.19dB (Table **2**).

Twenty patients were fitted in the right ear, 12 in the left, whereas one patient was fitted in both ears. The mean baseline aided word recognition score of the examined ear was 96.94%. Following the activation of the mobile phone the mean aided word recognition score of the examined ear declined to 95.65%. The measured difference (1.29%) proved statistically significant ($p < 0.05$).

Table 2: Demographic and Audiologic Data of Study Participants

Sample parameters	Value
Mean age	64.41 years
Male participants	23
Female participants	11
Right ear fitting	20
Left ear fitting	12
Bilateral fitting	2
Mean hearing loss (aided ear)	48.73dB
Mean hearing loss (both ears)	49.19dB

DISCUSSION

Hearing impairment refers to a limitation of function in an organ-level as measured by a persistently raised hearing threshold, compared to the hearing in the normal population [7]. This definition alone, however, is unable to adequately describe the social impact of that dysfunction (hearing handicap), because hearing problems can place considerable strain on interpersonal relationships, by making communication more difficult and affect social skills, or even everyday tasks [7, 8].

Despite this reality, however, it has been consistently reported [23, 24] that only about 20% of the people reporting hearing difficulties possessed hearing aids, although their use is associated with general improvements in health-related quality of life [3].

The main reasons given by hearing impaired individuals for not acquiring a hearing aid are primarily psychosocial in nature (i.e. potential stigmatization) [7, 25-27]. Furthermore, as much as 2.76 million people with hearing loss in the USA have tried but rejected hearing aids, and approximately up to 20% of those who returned their hearing aids, were reportedly driven to do so by an inability to use them while talking on the telephone [23].

This discrepancy, however, places major obstacles to the access in communication, which in turn is considered an essential pillar of modern Western societies. The problem may be exaggerated in the case of mobile phone technologies which have been one of the major constituents for our increasing communication capabilities, and may have a negative impact to the provision of both equal opportunities and fulfilment to hearing aid users [7].

Indeed, the introduction of digital wireless technologies in the mid-90s, which was basically brought about by the serious capacity limitations of analog networks and the additional services promised by digital ones [12], unveiled a compatibility problem between cellular phones and hearing aids, because of the audible EMI which is generated, when both are operating in close proximity [10, 11]. This drawback seems to be inherent to digital coding, and has also been reported with regard to various other types of hearing instruments, such as cochlear implants, or BAHA devices [28-31]. In addition, EMI from mobile phones has been implicated in hazardous incidents involving ICU equipment (ventilators, infusion pumps, renal replacement devices) [32], or more rarely patients with pacemakers [33] with potentially critical consequences.

The main source of interference in GSM mobile technology is considered to be the pulsing pattern of the electromagnetic waves which are emitted by the cell phone, and are being demodulated in the hearing aid amplifier, or picked up by other parts of the hearing aid [12, 33]. The frequency with which each pulse occurs (217Hz and its harmonics) falls within the audible frequency range [12, 21], and is perceived by the hearing aid user as a buzzing sound [13, 34]. In addition to the perceived annoyance, if the interfering output signal enters the working range of automatic gain control, high interference levels may affect the output of hearing aids and lead to a decrease in hearing aid gain [12, 13], whilst the buzzing sound can make speech understanding difficult, and may render the phone completely unusable to the hearing aid wearer [14].

As a result, 75% of hearing aid wearers in a study funded by the Hearing Concern Organization in Great Britain stated that they have experienced a lot or some interference and more than 50% reported a lot or some discomfort when trying to use a digital mobile phone [18]. The perceived annoyance has been associated with poor word and sentence recognition scores [12, 14]. Hence, in a study which involved measurements in 17 hearing impaired individuals, Hansen *et al.* demonstrated that the baseline input-related noise for a hearing aid user to be able to communicate through a mobile phone is approximately 47dB SPL for GSM networks [14], whilst a substantial decline in speech recognition scores was reported by Schlegel *et al.*

when the speech-to-noise ratio drops below 20-30dB SPL [35]. As a consequence, 60-80% of those who tried to use their hearing aid directly with a digital mobile phone have actually failed to do so [21, 35].

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. This bystander interference was also confirmed in other studies, though reportedly affecting a smaller percentage of hearing aid users [21, 36].

However, though the former studies indicated that a subjective annoyance was present as a result of this bystander effect, the potential impact of the latter in terms of word or sentence recognition scores had not been previously quantified. This was the aim of the present study.

Following a standard protocol, a statistically significant difference in speech perception was found in ITE hearing aid wearers after the activation of an advanced second generation mobile phone at close contact, due to the bystander EMI (Figure **1**). This is rather important as a finding, because the communication compatibility between digital hearing aids and mobile phones might influence not only the participation of hearing impaired individuals in our information society, but also their quality of life. Nevertheless, the clinical importance and the ensuing social impact of the observed decline in speech perception, in terms of a functional handicap of ITE hearing aid users, appear minimal.

Decreasing size has been a driving force in the history of ITE hearing aid development [3], in order to improve cosmetic appearance. ITE hearing aids largely alleviate social stigmatization, due to their miniaturized size, though they often prove unable to make the most of technological achievements, predominantly due to the minute distance between the microphone and the receiver. In addition, ITE hearing aids were so far regarded as more immune towards EMI, at least in comparison with behind-the-ear hearing aids. The more confined circuitry that they include was considered less probable to serve as an antenna; their decreased output also reportedly amplified the audible interference to a lesser degree [12]. Furthermore, the ITE models were associated with a further attenuation of the interfering electromagnetic signals by the soft tissues of the ear, and a more protected positioning of their microphone within the ear canal (that basically precluded them from receiving background noise). However, it seems that the whole theory is not applicable in modern devices [37], and the bystander effect of EMI has an impact, albeit limited, on the speech perception of ITE hearing aid wearers.

It should be noted that the measurement of hearing aid outcomes is particularly difficult, because there are numerous dimensions to consider (i.e. performance, satisfaction, benefit) with potential discrepancies in their respective scores [38]. Therefore, special attention was paid during the study 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. In order to preserve the integrity of the speech tests conducted, only hearing aids less than five years of age (a generally recognized mean hearing aid lifetime [21, 27]) were included in the study. Attention was also drawn to the standardization of the field environment produced by the mobile phone antenna, with regard to the relative position of the digital hearing aid [13, 21, 39]. Furthermore, the operating mobile phone was

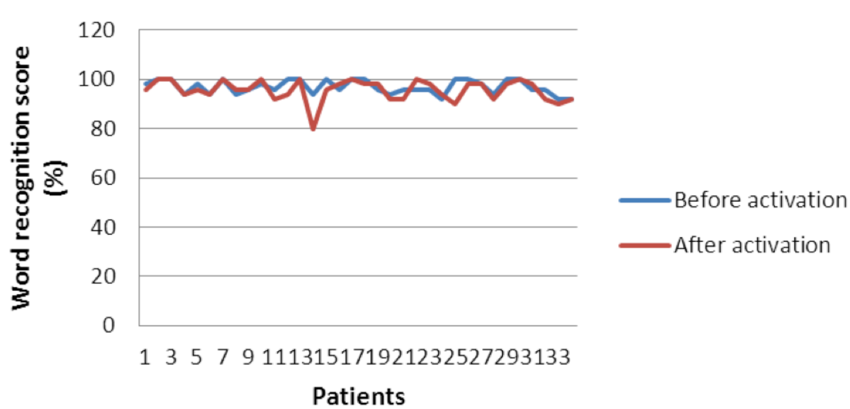

Figure 1: Word recognition scores before and after the activation of the mobile telephone (patient series).

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.

Although the mobile phone employed in the present study was not a 3G or smartphone model, 2.5G mobile phones still represent the market leader of cellular phones among more senior persons, who are more likely to be needing hearing amplification, due to their simpler user-phone interface, their lower retail price, and the reasonable additional utilities, which they can support. Hence, the observed results can be considered representative of everyday clinical practice.

It has also 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 [3]. Therefore, this period served as the minimum period of time, during which the participants in our study had been fitted with the hearing aids under evaluation. Moreover, the suspected entity of auditory deprivation was also taken into account during the construction of the research protocol. Auditory deprivation basically refers to a systemic decrease in auditory performance over time, associated with a reduced availability of acoustic information [3, 40]. However, all participants in our study had been consistent hearing aid wearers, therefore, a systemic bias from the potential impact of the auditory deprivation effect in our measurements was unlikely to occur [41-46].

CONCLUSION

The present study demonstrated that there is statistically significant difference in the speech perception of ITE hearing aid wearers after the activation of an advanced second generation mobile phone at close contact, due to the bystander EMI. Although, the clinical importance and the ensuing social impact of the observed decline in speech perception, in terms of a functional handicap of ITE hearing aid users, appear minimal, it seems reasonable for designing efforts to focus on establishing better hearing immunity for ITE hearing aids.

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CONFLICTS OF INTEREST

The authors did not receive any financial support and have no financial interest from this study. Mrs. Adria Stamou is an employee of Siemens-S. Stamou Co.

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