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The importance of acoustic reflex for communication

Kelly Cristina Lira de Andrade[a], Elizângela Dias Camboim[b], Ilka do Amaral Soares[b], Marcus Valerius da Silva Peixoto[a], Silvio Caldas Neto, PhD[c], Pedro de Lemos Menezes, PhD[a,*]

[a]Acoustic and Instrumentation Laboratory, Universidade Estadual de Ciências da Saúde de Alagoas, Brazil
[b]Faculdade de Fonoaudiologia, Universidade Estadual de Ciências da Saúde de Alagoas, Brazil
[c]Universidade Federal de Pernambuco, Brazil

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Abstract

Purpose: The purpose of the study was to compare the speech recognition capacity between listeners with and without acoustic reflex using different types of noises and intensities.

Materials and methods: We studied 18 women allocated to 2 groups: acoustic reflex present (20 ears) and absent (16 ears). They were presented with 180 disyllable words (90 to each ear), emitted randomly at a fixed intensity of 40 dB above the pure tone average hearing level. At the same time, 3 types of noises were presented ipsilaterally (white, pink, and speech), one at a time, at 3 intensities: 40, 50, and 60 dB above the pure tone average hearing level.

Results: The ages and auditory thresholds were statistically equal between the groups. There was a significant difference in mean number of hits between the 2 groups for the 3 types of noises used. There was also a significant difference in mean number of hits for noise type and intensity when white and pink noise was used at 40 and 50 dB and for all the intensities when speech was used.

Conclusion: Acoustic reflex helps communication in high-noise environments and is more efficient for speech sounds.

1. Introduction

Hearing is the main sense responsible for speech and language acquisition in children. A deficit in this function may compromise not only language development, but also social, emotional, and cognitive aspects [1].

The hearing mechanism, from the point of view of anatomists and physiologists, is described as comprising 3 divisions: external, middle, and inner ear. Each compartment of the ear has the particular function of allowing sound to be transmitted, amplified, and finally transformed into electric stimuli that travel to the cortex by the auditory nerve. The middle ear structures include the tensor tympanic muscle and the stapedius, the smallest striated muscles of the human body. The contraction of the tensor of the tympanum exerts force on the head of the stirrup bone, pulling it backward. The muscles exert forces in opposite and perpendicular directions to the movement of the ossicular chain [2].

Most information on the musculature behavior of the tympanum comes from experiments with animals. Several studies showed that acoustic reflex, even when submitted to unilateral stimulation, results in bilateral contraction, a finding subsequently used in clinical applications. Other studies proved the existence of a direct relation between duration of the stimulus and duration of the muscle contraction. Although acoustic reflex has been less studied in human beings, it has been observed that the contraction could be provoked by the simple exposure to intense sound [3].

The *stapedial reflex* is defined as a contraction of the middle ear muscles induced by intense acoustic stimulus. Because the acoustic reflex alters the mechanical properties

* Corresponding author. Laboratório de Instrumentação e Acústica, Universidade Estadual de Ciências da Saúde de Alagoas, Rua Jorge de Lima, 113–Trapiche, Maceió–AL CEP 57010-382. Tel.: +55 82 33156813; fax: +55 82 33156727.

E-mail address: pedrodelemosmenezes@gmail.com (P.L. Menezes).

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of the inner ear's transmission system, mechanical resistance can be measured indirectly. This makes it a valuable clinical and auditory research instrument in human beings [4-6].

As mentioned before, the tensor tympanic muscle pulls the handle of the malleus inward; and the stapedius exerts a backward force on the stirrup bone causing greater rigidity in the system and reducing sound transmission, mainly those from low frequencies, that is, those less than 1000 Hz. Thus, the changes in middle ear impedance, due to the above-mentioned contractions, have little or no effect on frequencies greater than 2000 Hz [3,7].

Both muscles seem to contract at practically the same time; and although the tensor tympanic seems to exert more force, the stapedius seems to be the more efficient muscle. In human beings, the acoustic reflex is generated at intensities of around 80 or 90 dB above the auditory threshold [8]. Some studies, however, prove the subclinical activation of this reflex, that is, with much smaller intensities than expected, mainly for noise [9,10].

Although some authors maintain that the main function of the acoustic reflex is to protect the auditory system, several limitations to this theory have long been known. The reflex is not efficient for attenuating sounds at frequencies higher than 1000 Hz and even less so at frequencies greater than 2000 Hz. Another limitation is the latency of muscular contractions, given that there is a determinate interval between the moment at which sound reaches the tympanum and the onset of muscular contraction. Thus, intense sounds may reach the auditory system and cause damage before the muscles can contract. These latencies, according to earlier studies, are approximately 0.06 second for the stapedius and 0.15 second for the tensor tympanic [3,7].

In addition, prolonged exposure to excessively high sound intensities, generally produced by man, may result in a diminished attenuating effect caused by fatigue. With constant sound stimulation, a continuous contraction is initially observed, followed by a gradual decrease until a state of rest is reached. Only one new contraction, altering substantially the stimulus frequency, will be generated [3,7].

Once the inefficiency of the acoustic reflex in protecting the auditory system was observed, several studies showed that the most important function of this reflex may be to improve speech discrimination, mainly in high-noise environments. However, one effect described in the literature is *antimasking*, defined as the reduction of low sound frequencies, be they environmental or from the individuals themselves. This mechanism allows the person to listen to higher-frequency sounds, that is, in the spoken communication range, by attenuating possible noise [11-15].

For low- to moderate-intensity sounds, the cochlea functions as a set of band-passing filters, that is, for intensities approaching the auditory threshold; however, the bandwidth is very narrow. As the intensity of the stimulus increases, the bandwidth gradually widens up to around 70 dB sound pressure level. The cochlea then behaves like a set of high-pass filters. This means that high-intensity stimuli start to stimulate auditory nerve fibers tuned to much higher than nominal frequencies. If the noises were not attenuated by the antimasking effect, high-frequency components of this noise, generated by high-pass filters, would mask speech frequencies and compromise discrimination [7,16].

Studies on patients with a section of the stapedius muscle tendon poststapedectomy and on individuals with facial paralysis, who did not have acoustic reflex, confirm the existence of this facilitating effect on speech recognition because they performed poorly on voice discrimination tests when compared with individuals with normal acoustic reflexes [11].

The contraction of the pupil as a response to intense light exposure and the contraction of the intratympanic muscles seem analogous. The purpose of the pupil is not to protect the eye from bright light because closing the pupil increases visual field depth. Similarly, the purpose of the acoustic reflex is not to protect the auditory system, but rather to accentuate speech perception by attenuating the low frequencies [7].

According to some authors [17,18], acoustic reflex alterations would cause more harm in terms of central auditory processing because this stapedius muscle mechanism seems to be directly related with the ease of capturing speech sounds, which would create better information-coding conditions and, therefore, speech intelligibility. According to some studies [19-21], individuals with auditory processing disorders may find their speech, reading, writing, language, and social behavior compromised.

In general, the acoustic reflex is important for separating the auditory signal from other internal or environmental noises and for controlling the attenuation of low-frequency speech sounds, thus favoring the perception of high-frequency sounds, the attenuation of voiced sounds, and the recognition of strong-intensity speech [22-24].

In light of the important limitations presented for the protective function of the acoustic reflex, given that there is still no consensus as to the communication function of this reflex, the purpose of the present study was to assess the role of the acoustic reflex in high-noise environment communication.

2. Materials and methods

The protocol of this study is based on Resolution No. 196/06 of the National Health Council of the Ministry of Health for research with human beings and was approved on November 3, 2006, by the Research Ethics Committee of the Universidade Estadual de Ciências da Saúde de Alagoas (protocol no. 603).

The study was conducted in the Universidade Estadual de Ciências da Saúde de Alagoas' Laboratory of Audiology. A sample of 18 women was studied, with a total of 36 ears. The participants were allocated to 2 groups: the acoustic reflex–

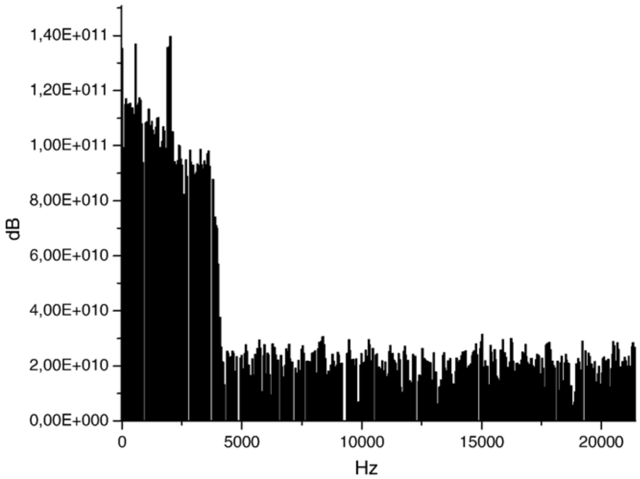

Fig. 1. Speech noise spectrum used for the discrimination test.

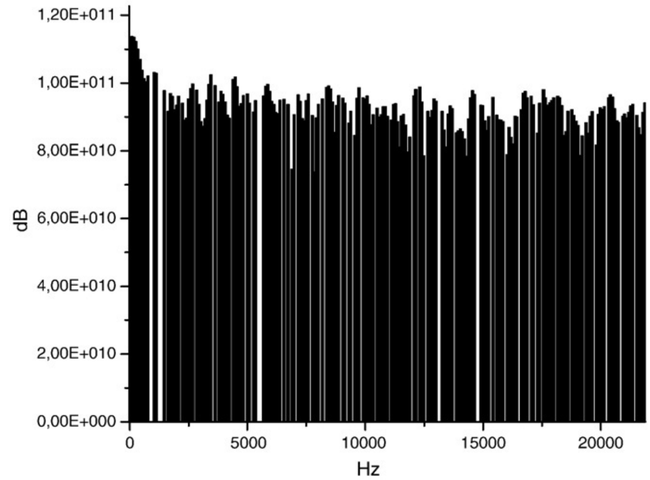

Fig. 3. Pink noise spectrum used for the discrimination test.

present group (20 ears) and the acoustic reflex–absent group, idiopathic reasons (16 ears). The number of subjects was defined by a calculation of sample size, which will be subsequently described.

The following inclusion criteria were adopted: auditory threshold less than or equal to 20 dB hearing level (HL) and age between 18 and 55 years. The exclusion criteria were exposure to occupational noise or recreational noise, previous ear surgeries, more than 3 ear infections within the last year, use of ototoxic drugs, and hereditary cases of deafness. The inclusion and exclusion criteria were considered for both groups, and the only difference between them was the absence or presence of acoustic reflexes at the frequencies studied (0, 5, 1, 2 and 4 kHz).

For subject selection, a questionnaire was applied, after which the informed consent form was read, explained verbally, and signed by the study participants. Data were then collected using the following procedures: otoscopy, pure tone audiometry, immittance audiometry, and the speech discrimination test. The otoscopy was conducted with sterilized specula to observe the integrity of the tympanic membrane. The pure tone audiometry was performed in an acoustic cabin. The psychoacoustic limit method, using the descending technique with 10-dB steps, was used to study auditory threshold; and response confirmation was determined by the ascending technique with 5-dB steps. Frequencies were assessed at one-eighth intervals between 0.25 and 8 kHz. The acoustic cabin followed ANSI 3.1-1991 recommendations. Immittance audiometry verified middle ear conditions and more specifically, those of the ossicle-tympanic system; acoustic reflexes were also studied at frequencies of 0.5, 1, 2, and 4 kHz. According to the immittance audiometry used, the intensity threshold for the study of ipsilateral and contralateral acoustic reflexes was 105 and 110 dB HL, respectively. Finally, a speech discrimination test was carried out in an acoustic cabin.

A total of 180 disyllable words (90 for each ear) were used for the discrimination test. These were randomly emitted at a fixed intensity of 40 dB above pure tone average hearing level (500, 1000, and 2000 Hz). The noises used were white, consisting of 10- to 10 000-Hz frequencies, where frequencies up to 6000 Hz at equal intensity and energy were

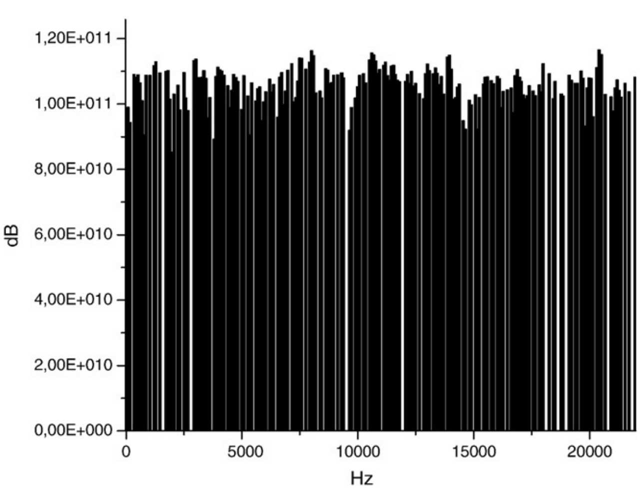

Fig. 2. White noise spectrum used for the discrimination test.

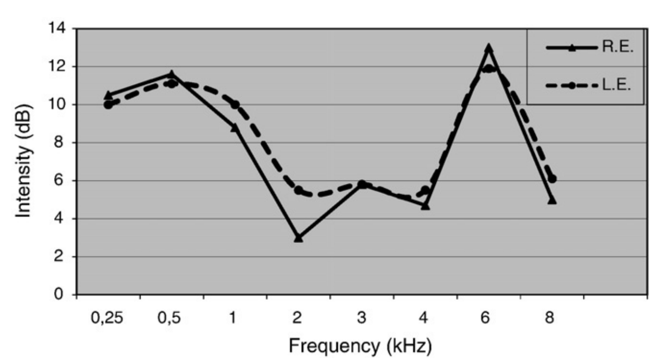

Fig. 4. Average of pure tone frequencies thresholds by ear. RE indicates right ear; LE, left ear.

Table 1
The auditory thresholds among the ears compared using the Mann-Whitney U test

Frequency (kHz)	0.25	0.5	1	2	3	4	6	8
P value	.81	.74	.42	.14	.98	.65	.76	.79

Table 2
The auditory thresholds by groups compared using the Mann-Whitney U test

Frequency (kHz)	0.25	0.5	1	2	3	4	6	8
P value	.44	.60	.38	.40	.86	.26	.30	.83

efficient; pink, which filters white noise and consists of frequencies of 500 to 4000 Hz, the band where it is most effective; and speech sounds [25]. The speech sounds of various individuals speaking at the same time were recorded to simulate a noisy environment. The frequencies ranged from 0 to 4.5 kHz. The noises used were at intensities of 40, 50, and 60 dB above pure tone average hearing level. That is, for each type of noise, 30 words per ear were provided; and after every 10 words, noise intensity was increased by 10 dB. Noise aspects were analyzed, and the fast Fourier transform of each one is shown in Figs. 1-3.

To be able to analyze the ears individually, the speech discrimination test was applied. The words and noises were emitted ipsilaterally. Only the hits were considered, that is, the words repeated correctly. The responses characterized as distortions were stored in a databank and will be analyzed in future studies. If the subject did not respond or responded incorrectly, the word was repeated once more after the next word on the list was presented.

The speech discrimination in noise test was inspired by the test developed by Santos and Schochat [26] and was performed with monosyllables or sentences at different intensity levels.

2.1. Data analysis

Sample size was calculated by the difference between the means, as follows:

$$\frac{\left(Z_{\alpha/2}+Z_{\beta}\right)^{2}.2(\sigma)^{2}}{d^{2}}$$

The parameters defined were α equal to .05, β equal to .1, and standard deviation of 3 dB. The minimum mean detection difference between the groups was established at 5 dB. Thus, the number of necessary samples found was 15 ears for each group.

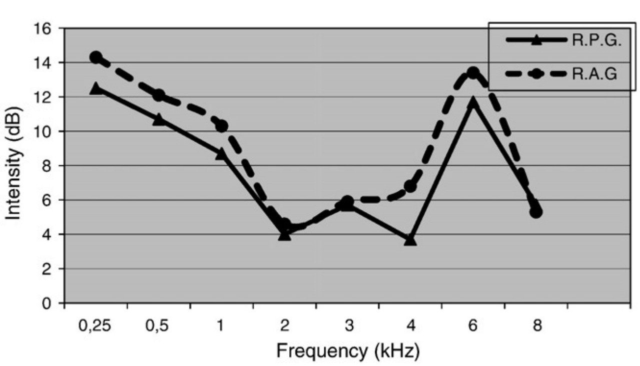

Fig. 5. Average of pure tone frequencies tested by group. RPG, reflex-present group; RAG, reflex-absent group.

To verify sample normality, the Kolmogorov-Smirnov test was performed. Student t test for normal distributions was then applied, or the Mann-Whitney U nonparametric test to investigate the differences between the 2 groups when at least one of the distributions was nonnormal [27].

The data were tabulated using Microsoft (Redmond, WA) Office Excel 2007 and processed by the Statistical Package for the Social Sciences (SPSS, Chicago, IL), version 16.0. The data were presented in tabular and graphic format showing the means, confidence interval of 95%, and standard deviations. The differences for all the tests were considered significant for P values < .05.

3. Results

The sample was composed of 18 women volunteers and included 20 ears for the acoustic reflex–present group and 16 ears for the acoustic reflex–absent group. The reflex-present group was aged between 29 and 37.5 years, with mean age of 33.3 years and standard deviation of 9.1. The age range for the reflex-absent group was between 29.9 and 41.2 years, with mean age of 35.6 and standard deviation of 10.5.

Sample normality was determined by the Kolmogorov-Smirnov test; however, normal distribution was only found for the mean number of hits by noise type. Thus, Student t test was used for this variable; and the Mann-Whitney U nonparametric test was used for nonhomogeneous variables (difference between ages, pure tone average hearing level, and mean number of hits by noise type and intensity).

Initially, the ages of the 2 groups (reflex absent and present) were described, compared, and found to be statistically equivalent (P = .814).

In relation to the frequencies tested by pure tone audiometry, the resulting thresholds are shown in Fig. 4. When the 2 ears were compared, no significant differences were found, as shown in Table 1.

Table 3
Acoustic reflex–present group contralateral reflex

Frequency (kHz)	0.5	1	2	4
Mean (dB HL)	87.7	92.5	88	81.7
95% Confidence intervals lower bound (dB HL)	82.8	87.9	82.7	77.5
95% Confidence intervals upper bound (dB HL)	92.6	97	93.2	85.9
Standard deviation (dB HL)	10.5	9.6	11.2	9

Table 4
The mean number of hits by noise type and intensity using Mann-Whitney *U* test

Noise type	White			Pink			Speech		
Noise intensity (dB SPL)	40	50	60	40	50	60	40	50	60
P value	.00	.00	.12	.00	.00	.13	.00	.00	.03

SPL indicates sound pressure level.

We compared the frequencies tested by pure tone audiometry, by group; the resulting thresholds are shown in Fig. 5. No significant differences were found, as shown in Table 2.

The contralateral reflex intensity, by frequency, was observed for the acoustic reflex–present group, as shown in Table 3.

The mean number of hits by noise type (white, pink, and speech) found for the 2 groups, using Student *t* test because the distributions were normal, showed a significant difference, with *P* values of .00 for each type.

We compared, using the Mann Whitney *U* test, the mean number of hits by noise type and intensity for the 2 groups, whose distributions for these variables were nonnormal, and found significant differences for the hits using white noise and pink noise at 40 and 50 dB, but not for 60 dB, above pure tone average hearing level. For speech sounds, we found significant differences for all intensities above pure tone average hearing level, as shown in Table 4.

4. Discussion

4.1. Discussion of the methods

The subjects with reflexes absent were selected from 1500 records in the Audiology Laboratory of the Faculty of Speech Therapy. Twenty of these met the criteria established, and 10 of these individuals were located. All the participants were women; and for this reason, the study was carried out with women only.

The use of pure tone average hearing level as parameter for speech and noise intensities was possible because the audiometric configuration of the subjects was linear, which ensures a very small or nonexistent difference between this mean and speech recognition thresholds [28].

The narrow relation existing between acoustic reflex and central auditory processing required the use and adaptation of the speech discrimination in noise test, consistent with the aims of this study. However, because this is a senior undergraduate paper, there was insufficient time to conduct the remaining assessment tests of central auditory processing. This will be done in a future study.

Given the importance of assessing otoacoustic emissions (OAEs) and of evaluating their suppression in the presence of noise, it may be important to describe these procedures in this study. The assessment of OAEs shows the specific function of external ciliated cells, and their presence indicates that the preneural cochlear receptor mechanism is able to respond normally to sound [29-32]. However, the device was out of order and not available to the Faculty of Speech Therapy. This situation will be corrected in a proposed new study.

The aforementioned problem, however, may have been minimized by the absence of differences between the audiometries of the 2 groups.

Suppressive effects are activated by the medial olivocochlear complex in the presence of noise and reduce the transduction potential of external ciliated cells. The existence of different OAEs between the groups, even if they were detected, does not ensure that these effects would be effectively assessed because the simplest spectra used, such as those of speech, have many low-frequency components less than 2 kHz. Thus, it would not be possible to accurately determine the percentage of suppression contaminated by the acoustic reflex action [9].

4.2. Discussion of results

Sample characterization showed that the ages and pure tonal auditory thresholds were statistically equal in the 2 groups. Thus, the samples were homogeneous in both groups, making it possible to describe each ear individually. The most relevant variable for observing the auditory system was the presence or absence of the acoustic reflex.

In this study, speech discrimination in noise generally improved in the group with reflexes present. We found no studies in the specialized literature that related acoustic reflex with different types of noise, especially using white and pink noise. Similarly, some studies [14] observed the ability of speech recognition with a competitive message, applying the Synthetic Sentence Identification test in adults in the presence or absence of the acoustic reflex. The results showed that the absence of contralateral acoustic reflex seems to interfere in the identification of speech signal in the presence of competitive noises.

The influence of the acoustic reflex on speech recognition responses in a monotic situation was analyzed using the Pediatric Speech Intelligibility test, and it was concluded that the reflex in question influenced auditory selective attention ability to recognize speech in the presence of noise [33].

Another study [34] also analyzed the influence of this reflex on speech test responses, in the presence of noise, relating auditory complaint and the ear tested. The results showed that the children with auditory complaint had no significant alterations in the speech test, but formed the largest group with acoustic reflex absent and/or altered.

The 3 types of noise at intensities of 40 and 50 dB above pure tone average hearing level showed greater speech discrimination efficiency in the group with acoustic reflexes present. For the 60-dB intensity, using white and pink noise, a similar percentage of hits was found between the 2 groups. This may be explained by a study [16] that reported that an increase in stimulus intensity activates the mechanism of the high-pass filter of the cochlea. This, in turn, stimulates the auditory nerve fibers tuned to much higher frequencies than their normal frequency, causing difficulties in discriminating speech sounds.

A second explanation must be the fact that white noise and pink noise lie in a fixed frequency range, which likely resulted in decreased attenuation of sound intensity at frequencies less than 1000 Hz, owing to intratympanic muscle fatigue. This fact, consequently, led to difficulties in speech sound discrimination. It was reported in other studies that a further contraction of these muscles is only generated by altering the stimulus frequency [3,7].

Furthermore, the acoustic reflex attenuates the low frequencies but is not efficient in attenuating frequencies greater than 1000 Hz and, even less so, those greater than 2000 Hz, with white and pink noise covering a large spectrum of frequencies. Therefore, the difficulty in discriminating speech is explained by the presence of higher noise frequencies not attenuated by the reflex during the entire test [3,7,15].

Better discrimination performance at all the intensities, including that of 60 dB, was observed when using speech sounds. Similarly, studies [33,34] observed improved speech sound discrimination in individuals with acoustic reflex present.

Speech sound has a variable frequency spectrum, with higher energy concentration up to 4kHz, different from the other types used. Moreover, the spectrum variation decreases intratympanic muscle fatigue, which optimizes the ability to discriminate speech in this case.

Let us suppose that all the subjects without acoustic reflex did indeed have disturbances in the central auditory process. Thus, it was to be expected that those with the reflex were more efficient in discriminating speech in all the conditions presented. This did not occur, given that, for the white and pink noises, at 60 dB, there was no significant difference between the 2 groups. Thus, a disturbance in the central auditory process, as a general rule, cannot explain the deficit in the communication mechanism. The fact, under the conditions described, however is perfectly explainable, in audition, by the mechanism of masking low frequencies.

5. Conclusion

The acoustic reflex, or some mechanism linked directly to it, for women, seems to have an important participation in speech sound discrimination in high-noise environments and is more efficient with sounds produced by articulated human voice, which, in the last analysis, improves communication. These findings, however, may be applicable between sexes.

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