Chapter 4

Suppression of Otoacoustic Emissions Evoked by White Noise and Speech Stimuli

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Abstract

Introduction: Suppressing otoacoustic emissions is one of the objectives, noninvasive methods that can be used to assess the efferent auditory system. When the ascending reticular activating system is stimulated, the cortex becomes more alert. The system reacts better to an important stimulus than an unimportant one.

Objective: Assess the effect of suppressing otoacoustic emissions by transitory stimulus in the presence of different auditory stimuli in normal listeners.

Methods: This cross-sectional, observational analytical study. The sample was composed of eight participants. The following procedures were adopted: recording otoacoustic emissions, suppression with white noise, suppression with white noise and pure tone, auditory training, new recording of suppression with white noise and pure tone, suppression using a speech pattern, suppression using a reversed speech pattern, suppression using familiar speech, and suppression using reversed familiar speech and suppression singing "happy birthday" in a familiar voice.

Results: There was a significant difference between the otoacoustic emission values, mainly at frequencies of 1000 and 1500 Hz.

Conclusion: Individuals submitted to the effects of suppression exhibit more effective results at frequencies of 1000 and 1500 Hz. Furthermore, it was found that the efferent activity of the auditory system is more efficient when it involves the use of the speech spectrum.

Keywords: audiology, suppression, efferent pathways, noise, speech perception

1. Introduction

Noise is defined as an undesirable sound, characterized by multiple amplitudes and frequencies that occur simultaneously in a nonharmonic fashion. It is increasingly common in several environments and often not considered harmful to hearing, but interferes directly in word comprehension and communication.

Speech recognition occurs in conjunction with acoustic, linguistic, semantic, and circumstantial cues. However, under favorable conditions, some of these cues may be disregarded. For the message to be transmitted efficiently, acoustic cues vary according to the situation and context of communication, such as in conversation and noisy environments [1, 2].

Speech comprehension is an important point to observe during audiological assessment, since it provides data on how individuals understand a spoken message in daily situations [3], which are generally associated with the presence of competitive noise. When presented with speech and competitive noise at the same time, even normal listeners often have greater difficulty hearing and understanding it [4]. These difficulties arise because several auditory channels are required to obtain speech recognition during the assessment process with noise, suggesting that more detailed sensory information is necessary in difficult-to-hear situations [5].

Assessment of speech perception is important in establishing the relationship between hearing ranges, using information obtained from audiological diagnostic procedures, and hearing performance, which is related to how the individual is developing functionally. For good speech perception, joint action of the auditory system is required. This involves the outer, middle, and inner ear, cranial nerve VIII, the retrocochlear portion, and the central nervous system [6].

During audiological assessment, speech comprehension difficulties can only really be observed with speech stimuli that represent a communicative situation [7], thereby providing important information on the capacity of the individual to recognize words in noisy environments [3, 8].

The conventional tests used to assess language comprehension are a microscopic view of auditory function [2, 9], and speech recognition evaluation in the presence of noise would be a more realistic way of assessing hearing [10, 11].

Otoacoustic emission (OAE) testing is a relatively simple, fast and noninvasive objective method. OAEs are defined as the release of sound energy from the inner ear when the cochlea is stimulated, reaching the external auditory canal. Sound waves are captured by a small probe introduced into this canal.

Their discovery contributed substantially to the creation of a new concept regarding the function of the cochlea, demonstrating that they are able not only to receive sounds, but also to produce acoustic energy [12]. This phenomenon is related to cochlear micromechanics, and it is suggested that when OAEs are generated in the cochlea, there is a mechanically active component coupled to the basilar membrane through which the reverse process of sound energy transduction occurs [13]. This property has recently been attributed to outer hair cells (OHC) and is controlled by efferent auditory pathways.

Suppression is characterized by a decrease in both the amplitude and peak phase of the emission. Test-retest comparison shows that the suppressive effects are repetitive and that suppressing OAEs is clinically useful in assessing and managing peripheral and central hearing loss [14].

Medial efferent fibers may inhibit this active contractile component of OHC, regulating low contractions with attenuation of rapid contractions, thereby decreasing the amplitude of OAEs, when they are affected by electrical, chemical, or noise stimulation [15].

The frequent complaints of speech recognition difficulties, primarily in noisy environments, even in those considered normal listeners from the quantitative standpoint, as well as discoveries of the active role of the cochlea, specifically OHC, are sufficient to prompt the investigation of new methods that can be used to help stimulate the structures responsible for speech recognition in situations of competitive noise.

2. Otoacoustic emissions, suppression and auditory pathways

Auditory perception occurs in three stages: a physical stimulus; a set of events through which a stimulus is transduced into a message of nerve impulses and a response to the message, frequently as perception or internal representation of sensations [16].

Sound is perceived through pressure waves, where this physical stimulus is transformed into an electrochemical stimulus, making it possible to convert auditory information into meaning. Part of our ability to make all this coherent owes to the fact that we develop models of what we expect to hear: phonemes, words, music, etc. [17].

Otoacoustic emissions (OAEs) are sounds created within the cochlea, spontaneously or as a response to acoustic stimulation [18]. OAE tests are used as an objective, noninvasive assessment of the first stages of sound processing, at the biomechanical activity level of the OHC [19, 20].

The olivocochlear bundle, the best known circuit in the efferent system, includes the medial and lateral tracts [21]. The lateral tract is composed of nonmyelinated fibers that terminate at the inner hair cells (IHC), located in the cochlea; and the medial tract consists of myelinated fibers that originate in the area around the medial superior olive connected to the OHC.

Although the role of the olivocochlear bundle in hearing performance has not been fully explained, some functions have been attributed to the medial efferent system: location of the sound source, auditory attention, improved hearing sensitivity, enhanced acoustic signal detection in the presence of noise, and a protective function [22]. Moreover, stimulating the efferent olivocochlear bundle decreases the neural response of the cochlea and auditory nerve [23].

Objective noninvasive methods can be used to assess the efferent auditory system, such as OAE suppression and obtaining an acoustic reflex [24]. OAE suppression occurs when noise is applied contralaterally, ipsilaterally, or bilaterally to the examined ear, assessing the activity of the medial olivocochlear efferent system [25].

Attenuating OAE responses in the presence of contralateral, ipsilateral, or binaural noise occur due to the action of medial olivocochlear tract fibers, via synapses in the ECC [26]. Competitive noise has an inhibitory effect on the functioning of the ECC of the cochlea, resulting in decreased OAE levels. The presence of this effect, called OAE suppression, in normal listeners shows the involvement of the medial olivocochlear system in the suppression of emissions [27, 28] and is not related to the presence of artifacts, interaural attenuation, or the effect of the middle ear [27].

Studies demonstrate a relationship between the population with speech recognition difficulties in noisy environments and the action of the medial olivocochlear efferent system. It has also been reported that this population exhibits less or no OAE suppression, suggesting a decline in the inhibitory effect of the efferent system [29, 30].

The cerebral cortex can exert a direct or indirect effect on sound processing, primarily via the superior olivary complex, thereby contributing to central auditory skills, such as speech recognition in noise [31].

With respect to the study of acoustic reflex, a number of investigations have found that the acoustic reflex threshold, captured at between 70 and 90 dB SL, can be reduced by a high-frequency facilitating stimulus presented before or simultaneously to a pure-tone activator of the reflex, characterizing a sensitization process [32]. This process is similar to the effect of OAE suppression, given that a suppressor stimulus reduces the range of responses.

Electrical stimulus of the olivocochlear efferent tract is capable of attenuating afferent auditory activity in the cochlea. Some efferent fibers exert spontaneous activity while others enter into activity after sound stimulation, suggesting a feedback system. This mechanism suggests that the olivocochlear efferent pathway plays an important role in discriminating messages in the presence of competitive noise [23].

2.1. Speech discrimination in noise X familiar speech

Although the ability to understand speech in noise is one of the functions attributed to the efferent auditory system, other anatomic structures are also involved, such as reticular formation. Evidence suggests that when the ascending reticular activating system is stimulated, the cortex becomes more alert and attentive. Thus, the system reacts better to an important stimulus than a nonimportant one. This may be one of the mechanisms involved in selective attention and the ability to hear in the presence of noise [33].

Studies describe the central auditory pathway as a flexible processing structure in which the descending feedback pathways play an important short- and long-term role in adaptive plasticity. These findings confirm the relationship between the efferent auditory system and auditory training in the presence of speech in noise [34].

Efferent auditory system activity, in terms of the medial olivocochlear system, has been implicated in the perception of speech in noise, in both children [35] and adults [36]. Therefore, it is necessary to investigate whether this system also plays a role in a training-induced improvement of speech perception in noise.

According to a cognitive model of voice perception in the analysis of the primary auditory cortex, vocal information is processed in three pathways that partially interact: (1) discourse analysis, preferentially in the left hemisphere, (2) vocal analysis of affective information, predominantly in the right hemisphere, (3) vocal identity analysis, involving voice recognition

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and semantic knowledge related to the individual, also predominant in the right hemisphere [37]. From this standpoint, different levels of cognition and awareness contribute to the analysis of auditory stimulus.

For familiar voice stimuli, there is strong desynchronization in the right hemisphere [38]. In line with this viewpoint, the study demonstrated that because of their biographic and emotional relevance, familiar voices are able to increase the level of cortical responses.

2.2. New findings

In order to assess the effect of transient evoked otoacoustic emission (TEOAE) suppression in normal listeners in the presence of different suppressor stimuli, a pilot study was conducted assessing eight individuals with no auditory complaints: five women (62.5%) and three men (37.5%), aged between 22 and 26 years (mean = 24.12). A total of 16 ears were analyzed [39].

TEOAEs were measured by an ILO apparatus, whereas suppressor stimuli, pure tones, and speech stimuli were emitted by a duly calibrated AC 40 audiometer. All the measurements were made three consecutive times, in order to calculate the average of the three, thereby increasing the reliability of the results.

TEOAEs were initially measured bilaterally. TEOAE suppression measures were recorded using white noise as a suppressor stimulus with an intensity of 60 dB above the speech recognition threshold (SRT) of the individual. The same measurement was taken, using a pure tone modulated at a frequency of 1000 Hz at 65 dB in the ear contralateral to the suppressor noise. Auditory training, consisting of three stages, was then conducted, as follows:

1. Presentation of stimuli emitted at a fixed intensity of 50 dB SL, at 500 and 1000 Hz and 1000 and 4000 Hz, without the presence of noise, with the aim of instructing the participant on identifying the reference stimulus at a frequency of 1000 Hz. The participant was asked to state whether the stimuli were equal or different.
2. Presentation of the same pairs of stimuli, at a fixed intensity of 60 dB SL, in the presence of white noise at an intensity of 30 above the SRT. The participant stated whether the stimuli were equal or different.
3. The stimulus at a frequency of 1000 Hz was randomly presented three times in a short period of time, at a fixed intensity of 75 dB SL, in the presence of white noise at an intensity of 55 dB SL. The participants were instructed to identify each stimulus by raising their hand.

After auditory training, three measurements were taken to determine the effect of suppression using white noise at 60 dB above the SRT simultaneously to present the pure tone at 65 dB also in the contralateral ear, in order to analyze the amplitude of TEOAEs with a pure tone stimulus at 1000 Hz after training.

The effect of suppression was measured in the presence of balanced sentences from the HINT protocol, emitted by standard speech as suppressor noise. The effect of suppression was then measured in the presence of reverse sentences from the HINT protocol as suppressor noise.

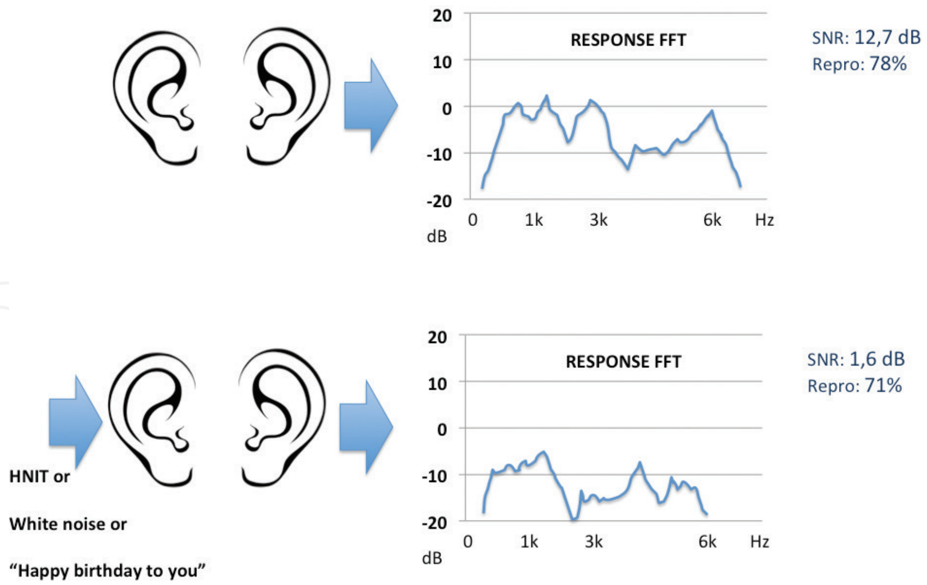

Figure 1. The effect of suppressing TEOAEs using 1 kHz stimuli (above) and using speech as suppressor noise (below).

The effect of suppression was measured in the presence of white noise and the same balanced sentence from the HINT protocol was presented using speech familiar to the subject. The sentence was presented orally by the subject's mother or sister using an AC 40 audiometer. The same occurred with the ensuing measurements, where the reverse sentence from the HINT protocol was presented using familiar speech.

Finally, the effect of suppressing TEOAEs was measured, using the "Happy Birthday" song emitted, using familiar speech as suppressor noise, as shown in **Figure 1**. All the speech stimuli as suppressor noise were emitted at an intensity of 60 dB above the speech reception threshold (SRT) of each participant.

TEOE*	Mean (dB)	Standard deviations (dB)	*p*-Values
1000 Hz	12.72	6.84	0.000*
1000 Hz + white noise	0.14	7.49	
1500 Hz	15.30	6.02	0.000*
1500 Hz + white noise	4.50	9.30	
2000 Hz	9.92	5.25	0.392
2000 Hz + white noise	9.04	5.99	
3000 Hz	7.70	6.04	0.468
3000 Hz + white noise	7.31	6.23	
4000 Hz	6.82	5.48	0.182
4000 Hz + white noise	6.18	5.51	

*Siginificance.

Table 1. Transient-evoked otoacoustic emissions and the effects of suppressing these emissions in the presence of white noise.

TEOE*	Mean (dB)	Standard deviations (dB)	*P*-values
1000 Hz	12.72	6.84	0.000*
1000 Hz + white noise+ 1000 Hz	-1.07	6.16	
1500 Hz	15.30	6.02	0.000*
1500 Hz + white noise+ 1000 Hz	5.61	5.86	
2000 Hz	9.92	5.25	0.316
2000 Hz + white noise+ 1000 Hz	9.30	5.63	
3000 Hz	7.70	6.04	0.742
3000 Hz + white noise+ 1000 Hz	7.84	6.51	
4000 Hz	6.82	5.48	0.379
4000 Hz + white noise+ 1000 Hz	6.43	5.52	

*Siginificance.

Table 2. Transient evoked otoacoustic emissions and the effects of suppressing these emissions in the presence of white noise and pure tone at a frequency of 1000 Hz before auditory training.

According to the analyses, the *t*-test showed a suppression effect at all the frequencies tested in all the individuals. However, when TEOAEs and suppression values were compared, a statistically significant difference was observed only for frequencies of 1000 and 1500 Hz ($p < 0.01$), as shown in **Table 1**.

Comparison between TEOAEs and the effect of suppression using a pure tone at 1000 Hz shows a statistical significance also for frequencies of 1000 and 1500 Hz ($p < 0.01$), as demonstrated in **Table 2**.

When the mean suppression values were compared using the balanced HINT sentence, the *t*-test showed a statistically significant decline in the amplitude of TEOAEs at frequencies of 1000 and 1500 Hz (**Table 3**).

It was also found that the suppression amplitude, using the normal balanced HINT sentence, was much greater than the mean suppression values using white noise. There was a statistically significant difference for the frequencies of 1000 and 1500 Hz (**Table 4**).

There was also a decrease in the suppressor effect of the “happy birthday” song compared to the normal balanced HINT sentence using standard speech. In this case, a statistically significant difference was observed only at a frequency of 1000 Hz (**Table 5**).

The present study showed that all the statistically significant suppression results occurred at frequencies of 1000 and 1500 Hz. Other studies have demonstrated that the suppression effect occurs at specific frequencies [28, 40]. A study that conducted in adults with normal hearing thresholds and no auditory complaints found that frequencies of 1000–2000 Hz exhibited a greater suppression effect [41]. Another study analyzed the effect of contralateral noise and a complete lesion of the olivocochlear system on the action potentials of the auditory nerve in cats, showing that contralateral noise decreased the action potential of the auditory nerve,

TEOE*	Mean (dB)	Standard deviations (dB)	*P*-values
1000 Hz	12.72	6.84	0.004*
1000 Hz + standard speech_HINT	7.40	6.45	
1500 Hz	15.30	6.02	0.007*
1500 Hz + standard speech_HINT	11.12	6.88	
2000 Hz	9.92	5.25	0.105
2000 Hz + standard speech_HINT	8.06	6.09	
3000 Hz	7.70	6.04	0.824
3000 Hz + standard speech_HINT	7.56	6.14	
4000 Hz	6.82	5.50	0.340
4000 Hz + standard speech_HINT	6.30	5.92	

*Siginificance.

Table 3. Transient evoked otoacoustic emissions compared to the effect of suppressing these emissions in the presence of the normal balanced HINT sentence emitted in standard speech.

TEOE*	Mean (dB)	Standard deviations (dB)	*P*-values
1000 Hz + white noise	0.13	7.48	0.008*
1000 Hz + standard speech_HINT	7.40	6.45	
1500 Hz + white noise	4.50	9.30	0.017*
1500 Hz + standard speech_HINT	11.12	6.88	
2000 Hz + white noise	9.04	5.98	0.278
2000 Hz + standard speech_HINT	8.06	6.09	
3000 Hz + white noise	7.31	6.23	0.542
3000 Hz + standard speech_HINT	7.56	6.14	
4000 Hz + white noise	6.18	5.51	0.815
4000 Hz + standard speech_HINT	6.30	5.92	

*Siginificance.

Table 4. Effect of suppressing otoacoustic emissions by transient stimulus in the presence of white noise compared to suppression using the normal balanced HINT sentence emitted with standard speech as suppressor noise.

and that the section of this system overrides the inhibitory effect of the nerve [42]. In this study, the highest inhibition values were found at frequencies of 1000–2000 Hz. Other studies have confirmed that the suppression effect is more effective at low frequencies, despite the fact that the olivocochlear bundle is thicker in the basal portion of the cochlea [43, 44].

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TEOE*	Mean (dB)	Standard deviations (dB)	*P*-values
1000 Hz + standard speech_HINT	7.40	6.45	0.038*
1000 Hz + happy birthday	4.13	7.92	
1500 Hz + standard speech_HINT	11.12	6.88	0.489
1500 Hz + happy birthday	9.87	8.27	
2000 Hz + standard speech_HINT	8.06	6.09	0.579
2000 Hz + happy birthday	7.17	7.22	
3000 Hz + standard speech_HINT	8.14	6.34	0.285
3000 Hz + happy birthday	7.13	6.37	
4000 Hz + standard speech_HINT	6.53	6.11	0.781
4000 Hz + happy birthday	6.65	5.40	

*Siginificance.

Table 5. Effect of suppressing otoacoustic emissions by transient stimulus in the presence of standard speech compared to using the "happy birthday" song as suppressor noise.

The results of stimuli before and after auditory training show no statistically significant differences for the frequencies tested. However, a study that investigated the involvement of the medial olivocochlear system in perceptual learning found a significant improvement in responses and olivocochlear system activity after 5-day auditory training with 16 normal listeners, using a phonemic discrimination task, when compared to a control group [34]. Other studies demonstrated growing evidence that the adult auditory cortex is a dynamic and adaptive processing center. This has been shown in auditory perceptual learning studies, in which long-lasting neuronal changes were observed in the auditory cortex of animals [45, 46] and human beings [47, 48] after intensive auditory training.

Comparison between the suppression effect using white noise and that using a normal-balanced HINT sentence demonstrated that suppression amplitude using the spoken sentence in the contralateral ear was far greater than the mean suppression values using white noise. This finding is possibly explained by the fact that speech demands more attention, albeit unconsciously, from the individual. This corroborates a study conducted with normal listeners, who were asked to detect sounds at a particular frequency in the contralateral ear simultaneous in the presence of background noise [49]. It was concluded that contralateral suppression of OAEs was greater when attention was directed to the contralateral ear. Another study analyzed the suppression effect in adult women in four situations: (1) with no contralateral stimulation; (2) with contralateral stimulation at 60 dB SPL; (3) with contralateral stimulation at 60 dB SPL and words simultaneously emitted in the test ear, and the patient required to recognize the semantic field of these words; and (4), identical to situation (3), without having to recognize the words. The authors observed that the effect of suppression was higher in situations 3 and 4, in which more attention to speech was required, concluding that the cortical structures controlled efferent activity in the auditory system, primarily in situations involving the use of the speech spectrum [50]. A comparison between speech suppression using a standard sentence and the "happy birthday" song revealed that the suppression effect was lower with the song, possibly because it involved automatic predictable speech, given that the song is universally known. In this case, attention to the suppressor stimulus was lower, causing fewer changes in cochlear activity and a smaller reduction in OAEs amplitude. However, to confirm this hypothesis, more research using speech as suppressor stimulus is needed, since we found no studies along these lines. Another study aimed at determining the best conditions to assess the efferent auditory system. The authors assessed 11 adults with normal thresholds, using three suppressor stimuli: clicks, narrow band noise, and pure tones. It was found that the click and pure-tone stimuli were the most and least effective suppressors, respectively [47]. Speech, however, was not considered.

The authors concluded that suppressing TEOAEs in normal listeners is more effective at low frequencies, specifically at 1000–1500 Hz. Moreover, the efferent activity of the auditory system is more efficient when suppression involves a speech stimulus, compared to white noise, which has no significant effect. The efferent auditory system is more alert and attentive to standard speech stimuli, but less efficient when this speech is automatic [39].

2.2.1. Personal experience regarding the present study

The experience of conducting this study was very rewarding and indeed resulted in important findings for a more detailed investigation. For example, a reasonable variability was observed in TEOAE amplitudes, regardless of the presence of a suppressor stimulus using the same testing standards (same ear, same professional, same acoustic environment, etc.). This variability was observed when the tests were repeated. To minimize this problem, the tests were repeated three times and the average computed. However, future studies will involve five repetitions to decrease variability and provide even more consistency. Furthermore, posttraining results were not statistically significant, possibly due to the short duration. Data in the literature suggest the need for more robust training that can guarantee better learning on the test, in order to be able to observe differences [34, 45–48].

3. Final considerations

Given that the ability to recognize speech is one of the most important measurable aspects of auditory function, the tests used in clinical practice are of the utmost importance for audiological diagnosis.

Studies that allow more thorough assessment of individuals with speech comprehension difficulties in noise should be encouraged, since understanding the entire mechanism involved in this dynamic, from sound detection to comprehension, will make it possible to standardize auditory tests and design therapies for specific stimulations.

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Glossary

dB—decibels

dB SPL—decibels sound pressure level

dB SL—decibels sensation level. The amount in decibels by which a stimulus exceeds the hearing threshold

OHC—outer hair cells

HINT—hearing in test noise

Hz—Hertz

IHC—inner hair cells

OAEs—otoacoustic emissions

TEOAEs—transient evoked otoacoustic emissions

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