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Research Article

The Effect of a Words-in-Noise Training Method on Speech Perception in Noise of Children with Unilateral Hearing Loss

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Highlights

- Unilateral hearing loss decreases speech in noise understanding
- Auditory training decreases adverse unilateral hearing loss effects

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ABSTRACT

Background and Aim: Despite more affordable and advanced technologies for early detection of congenital hearing loss, unilateral hearing loss is the prevalent form of hearing loss affecting school-aged children. This study aimed to examine the impact of Words-in-Noise (WIN) training on speech perception of noise in children with unilateral hearing loss.

Methods: Thirteen children aged 8 to 12 years with unilateral hearing loss underwent a WIN training program in noise. The participants were tested before and after training on word identification in noise and cortical auditory evoked potentials.

Results: A comparison of the mean signal-to-noise ratio 50% between pre- and post-training indicated that signal-to-noise ratio 50% score decreased after training sessions. WIN training reduced the latency in N1 and P2 waves in the Fz electrode and the N1 wave in the Pz electrode and increased the amplitude of the waves in the Fz and Pz electrodes. The observed data suggest that all participants' performance improved on word identification in noise and some electrophysiological parameters. Cortical auditory evoked potentials components changes did not correlate with the WIN scores.

Conclusion: The Persian version of the WIN training improved speech perception ability in the presence of competitive noise in children with unilateral hearing loss. Therefore, this software solution can partially solve speech comprehension problems with noise in these children.

Keywords: Unilateral hearing loss; word in noise training; children; listening in noise

Introduction

As defined in previous studies, Unilateral Hearing Loss (UHL) occurs when hearing is normal in one ear and abnormal in the other. The incidence of UHL in newborns is between 0.83 and 2.7 per 1000 births [1-3]. The average age of early diagnosis of UHL has decreased over the years, reaching about 2.6 years after the implementation of newborn screening programs. The etiology of UHL is different and unknown in many cases; however, previous research has shown viral agents, genetic background, meningitis, and head trauma can cause UHL [4, 5].

Although it is well known that bilateral hearing loss is a major cause of speech and language problems in children, studies conducted during the 1980s and 1990s have shown that children with UHL have more problems at school than children with normal hearing. They drop out of school, need more educational support, and have more behavioral problems [3, 6, 7]. UHL also has devastating effects on sound localization and speech discrimination under adverse listening conditions [7]. Evidence shows that UHL delays speech and language development [8]. Hearing in noisy environments is the most important problem for people with hearing loss and auditory processing disorders [9].

It is essential to note that binaural hearing relies on three mechanisms to provide speech perception in noisy situations. These mechanisms include binaural summation, release from masking or squelch effect, and head shadow effect. Since people with UHL have lost the benefits of binaural hearing, they require a higher Signal-to-Noise Ratio (SNR) for speech perception in noise. People with UHL have many difficulties with speech perception in noise. However, some people can partially compensate for these problems with single-ear audio cues [10]. Hearing difficulties in background noise have at least three basic components. The first issue is difficulty in selecting and receiving speech from background noise. Noise suppression ability is carried out in the cochlea and brainstem and is controlled by the brain. The second component is poor auditory decoding ability. Auditory decoding is a key factor in speech understanding. A person with poor decoding ability will receive less information from a speech in a noisy environment than in a quiet environment. The third factor, which Katz calls the limbic effect, is the impact of the limbic system on a person's mental and emotional state. For people with hearing loss in noisy environments, the limbic system may cause dissatisfaction with the listening context [11].

Current rehabilitation strategies for this disorder include the amplification of Contralateral Routing of Signal (CROS) hearing aids, Bone-Anchored Hearing Aid (BAHA), and FM systems [12-14]. Nowadays, CROS hearing aids are considered the first step to helping people with UHL. Compared to BAHA, this hearing aid type is not expensive and does not require surgery. This treatment option brings many problems and psychosocial consequences for the person. Among them, we can mention the social effects of hearing loss, the lack of comfort caused by the blockage of the better ear canal, and generally poor hearing improvement. BAHA hearing aids are also an effective treatment for UHL, but they are relatively expensive and require surgery. Their usefulness, however, is also limited [15]. Improved speech perception in noise could provide efficient and non-invasive management for children with UHL and may also help typically develop language, speech, and educational achievements in these children. Regardless of receiving the appropriate amplification, it is vital to use appropriate listening training methods to increase their abilities to understand speech perception in noise. Hence, in this paper, we investigated Word-in-Noise (WIN) training in children with UHL to determine whether this training could help them improve their understanding of speech in the presence of background noise.

It has been shown that WIN training exerts a psychological benefit by desensitizing the limbic system to noise, which is its most important benefit [11]. The general objectives of WIN training can be divided into two groups: improving the ability to understand speech in the presence of background noise and enhancing a person's sound tolerance [16]. Rehabilitation and auditory training strategies have been used for UHL, although the number of these studies is very scarce. For example, Firszt et al. evaluated the localization abilities of this group of patients with training, and the results before and after training were significantly different [17].

The study of cortical auditory responses has been considered because it can highlight the differences in cortical processing of auditory information based on the type of rehabilitation. These types of responses can also identify neurophysiological indicators (such as P1 wave latency) because young children have prominent P1, and the maturation rates for the PI latency in these children are better to track [18]. This type of response has been widely used in hearing-related research, leading to diagnosing and monitoring auditory development in children. Such responses can assess auditory maturity, auditory capacity, and speech perception in the noise of children with or without hearing loss [19, 20].

Several studies have reported that speech perception of noise is impaired in children with UHL. Furthermore, many reports indicate that hearing aids and assistive devices would not help these children [1, 2]. This study aimed to apply and suggest a new training approach to managing children with UHL.

Methods

A clinical trial study with code IRCT20161206031257N2 was conducted. Thirteen children (8 boys and 5 girls with a mean±SD age: 9.76±1.69; range 8–12 years) with UHL participated in this study. The UHL was in the left ear for 5 participants and the right ear for 8 participants. Based on a 6-frequency pure tone average at 0.5, 1, 2, 3, 4, and 8 kHz, the mean hearing in the better ear was ≤20 dB HL. Based on a 4-frequency pure tone average at 0.5, 1, 2, and 4 kHz, mean hearing in the poorer ear was between 55 and 70 dB HL for 4 participants (moderate HL) and 71 to 90 dB HL for 9 participants (severe HL).

For all participants, the Persian version of the WIN test was conducted [21]. To perform the test, first, the CD player is connected to the audiometer input (MADSEN Astera GN Otometrics, Denmark). The test material is provided to the patient via the circumaural headphone (TDH-39, Philips).

In short, the process of creating the test was as follows: 118 mono-syllabic words were selected that were most frequent and common among the age range of 7 to 12 years. The selected words for each age group were from the basic Farsi vocabularies of the Persian-speaking children. To determine its content validity and reliability, the word lists were given to 10 experts in this field, and the Content Validity Ratio (CVR) was used for each mono-syllabic word. Then all verified words were recorded by a female talker in an acoustic studio. Finally, 70 mono-syllabic, phonetically balanced words were selected. The final selected words were combined with an accompanying babble noise, including 6 speakers. This test includes two lists of 35 words and is presented in 7 different SNR levels. For the accurate presentation of the words at each of 7 SNRs from +24 to 0 dB SNR in 4 dB decrement steps in the presence of babble noise, the output level of the audiometer was set at a comfortable listening level, individually. WIN implemented monaurally using the better ear. Each list was scored based on the number of correct responses at each SNR, and SNR 50% score was calculated using the following equation:

50%=i+1/2 (d)–(d) (#correct)/(w) in which i denotes the initial presentation level (+24) SNR, d refers to the size of decrement step (4), w is the number of words (5 words) in each step, and correct shows the number of words that were repeated correctly in each list [21].

Electroencephalography (EEG) was recorded using EB-Neuro (Be-plus, S.P.A, Italy) in a soundproof booth. The participants were seated in comfortable chairs, watching muted movies of their choice. Participants were instructed to sit while ignoring the receiving stimuli. The examiner was seated inside the soundproof booth to monitor the participants' state. The overall duration of each EEG session, including electrode placement and EEG recording, was 30 minutes.

Cortical potentials were stimulated using a 30-ms Consonant-Vowel (CV) speech phoneme /da/. The stimuli were presented randomly using a loudspeaker with an inter-stimulus interval of 800 to 1100 ms. Two hundred epochs were collected for each subject. The artifact rejection level was set at 150 µV. During testing, the children were seated facing a loudspeaker positioned at a 1-m distance at 0° azimuths. Speech stimulus /da/ was presented in a continuous babble noise at +10 dB SNR; the output level was 75 dB SPL. The electrode montage includes the active electrodes placed at Fz, Cz, and Pz referenced to M1 and M2. The ground electrode was located on the forehead. Electrodes impedances were kept below 10 kΩ. The recording window included a 100 ms pre-stimulus and 1000 ms post-stimulus time. Incoming evoked responses were filtered from 0.1 to 25 Hz. The Cortical Auditory Evoked Potentials (CAEPs) have been extracted offline via Galileo software.

Word-in-noise training

The target stimuli included mono-syllabic words from the book of frequent Persian vocabulary. In the first step, more than 1000 mono-syllabic, most frequent, and common words were chosen. The selected words were proportional to each age group. After that, the selected words were given to specialists such as audiologists and speech therapists to determine their content validity. Afterward, the confirmed words, close to 600 words, were recorded by a male talker familiar with phonetics in an acoustic studio. After a phonetic examination of the words by a specialist, fifty 10-word lists (a total of 500 words) were prepared. The word lists were intensively normalized by Cool Edit on the level of the average RMS of –25 dB with an attack and release time of 210 ms. The noise of 8 speakers was considered to create a competitive noise. For these speakers, 8 related texts were prepared, and 4 male and 4 female speakers were asked to read their texts aloud and simultaneously without interruption. After collecting the sounds, their intensity was set equal to –25 dB average RMS using Cool Edit software, and 2.7 seconds intervals were considered for each babble noise. The intensity level of all of them was the same and finally combined. Therefore, the final noise file of the 8 speakers did not have any distortion [22].

The training began in the week following the pre-training test. The participants attended eight 45-min sessions twice weekly [23, 24]. The training was conducted using a clinical audiometer (Madsen Astera GN Otometrics A/S, Denmark), and the training material was delivered to the better ear via headphones in a soundproof booth. To perform the training in the presence of noise, the participants were first presented with 1 of 10 lists without noise to become familiar with the type of words and how to respond. Then the actual training began. The easiest type of training was when the SNR of the 8 multi-talker was high. During the training, the level of the target stimuli was fixed at 62 dB. The level of the masker varied throughout the training. At each level, the participant's errors were recorded. Errors include mispronouncing a word, skipping a letter, or not pronouncing the entire word. There were 10 monosyllabic words in each list. Starting the first session, the SNR was set at +12 dB and then varied adaptively. Specifically, the SNR was:

1) decreased by 2 dB if the participant scored ≥92.5% on 8 lists 2) increased by 2 dB if the participant scored <92.5%. If the score remained<92.5% for the second time, the trainer either maintained the SNR and used a list of new stimuli that were less challenging, or increased the SNR by 2 dB and used a list of new stimuli that were equally challenging to the previous list. The lowest SNRs were recorded and used as the starting SNR for the next session. If the participant could reach the final level, the SNR of 0 dB, or had a score≥92.5% in this ratio and ratios close to 0 (e.g., 2 and 4 dB), this ability indicated the participant's adequate functioning in these exercises. At the end of each session, the participants received a small prize as a reward.

Data analysis

Offline analysis of EEG was implemented using Galileo software to extract CAEPs waveforms with an epoch time of 100 to 1000 ms. CAEPs were digitally band-passed filtered 0.1–25 Hz (24 dB/octave). Also, 200 epochs were averaged for each participant. Electrophysiologists manually determined P1, N1, P2, and N2 peak latencies and amplitudes. These cortical components were identified across all recorded electrodes. The main criteria to label the cortical components was looking for the highest (positive peak) and lowest (negative peak) data points within CAEPs waveforms.

To determine the effects of noise on latency and amplitude data for the P1, N1, P2, and N2 peaks, with age as a covariate and electrode locations (Fz, Cz, and Pz), repeated measures were performed. Main effects and interactions were regarded as significant if $p<0.05$. Planned comparisons were performed only when significant main effects or interactions were obtained. Separate ANOVAs were undertaken to determine 1) whether pre- and post-training showed SNR 50% changes during 8 seasons in UHL children and 2) whether 8 sessions were associated with changes in CAEPs in the UHL children. The Pearson correlation coefficient was used to investigate the relationship between CAEP components and WIN scores.

Results

Effect of training on word-in-noise scores

The mean of SNR 50% of list 1 pre-training was equal to 4.03 dB (SD=2.89); for list 2, it was 2.30 dB (SD=1.83). For post-training, it was 1.75 dB (SD=1.32) and 1.13 dB (SD=1.04), respectively, for list 1 and 2 (Figure 1). A comparison of the mean score of SNR 50% between pre- and post-training indicated that the SNR 50% of each list decreased after training sessions. There was a statistically significant difference between the mean scores of pre- and post-training among the participants ($p<0.05$).

Effect of training on cortical auditory evoked potentials measures

The average amplitude and latency of the CAEPs waves for all channels (Fz, Cz, and Pz) pre- and post-training are given in Table 1. Results showed that the latency of N1 ($p=0.016$) and P2 ($p=0.006$) waves recorded in the Fz electrode, the latency of the N1 wave ($p=0.002$) recorded in the Pz electrode, and the N1-P2 complex ($p=0.009$) recorded in the Fz electrode, Pz electrode ($p=0.007$) after training were significantly different from the wave latency before training. The latency of the recorded waves from these regions has been significantly reduced.

There are significant differences between the amplitudes of waves P1, N1, P2, and N2 recorded in the Fz electrode ($p=0.002$, $p=0.005$, $p=0.003$, and $p=0.003$, respectively). The amplitudes of waves P1 ($p=0.006$) were

Table 1. Mean latencies (ms) and amplitudes (µv) of P1, N1, P2, N2, and N1-P2 components elicited to /da/ in noise for the pre and post-training (n=13)

Peak		Pre-training		Post-training		p	
		ms	µv	ms	µv	ms	µv
Fz	P1	69.31±4.70	4.81±1.86	67.71±1.84	6.70±1.56	0.463	0.002
	N1	106.74±9.22	5.05±2.65	101.91±8.12	6.82±1.73	0.016	0.005
	P2	143.00±5.74	6.98±2.49	133.49±5.37	9.46±1.28	0.006	0.003
	N2	226.04±3.06	11.13±1.61	225.20±2.99	13.90±1.99	0.345	0.003
	N1-P2	36.25±6.87	1.93±1.59	31.58±3.33	2.63±1.16	0.009	0.345
Cz	P1	63.70±6.89	3.82±1.25	62.34±4.92	6.64±1.80	0.600	0.006
	N1	105.76±9.88	4.78±1.11	107.09±5.79	4.55±0.94	0.272	0.382
	P2	138.54±4.88	5.67±0.87	140.98±6.42	5.09±0.91	0.101	0.173
	N2	222.27±6.31	12.09±1.46	224.00±6.41	11.44±1.18	0.221	0.173
	N1-P2	32.78±13.08	0.89±1.60	34.00±11.82	0.54±1.50	0.638	0.507
Pz	P1	64.26±3.63	3.92±1.39	62.71±2.81	5.57±1.11	0.133	0.005
	N1	115.32±5.17	5.43±1.30	102.52±6.66	5.00±0.89	0.002	0.133
	P2	138.02±5.16	5.99±1.20	134.00±4.54	6.31±1.02	0.124	0.311
	N2	218.23±3.74	10.29±1.43	215.23±4.44	11.88±1.77	0.087	0.005
	N1-P2	22.69±5.25	0.55±1.25	31.47±5.39	1.06±1.28	0.007	0.279

recorded in the Cz electrode. The amplitudes of waves P1 (p=0.005) and N2 (p=0.005) were recorded in the Pz electrode after training compared to their amplitudes before training. This means that the amplitude of the waves recorded in these cortical regions has increased significantly. Figure 2 shows the average of the CAEP waves recorded in all three brain regions of the 13 participants before and after training.

Correlation between cortical auditory evoked potentials components and word-in-noise scores

The Pearson correlation coefficient was used to analyze the relationship between the two tests. Also, the average of CAEP test waves recorded in three channels was used for a better understanding and more general view of this relationship. There is no significant relationship between the amplitude and latency of CAEPs test waves and scores of lists 1 and 2 of the WIN test (p>0.05).

Discussion

This study examined the benefits of a rehabilitation program for children with UHL, who often suffer from hearing problems in the presence of noise. It became clear that the participants' ability to respond and tolerate noise increased as we approached the final sessions of the training. Indeed, although the noise level increased significantly from sessions 6–8, there were no significant changes in the percentage of correct responses during that time, consistent with previous findings and studies [24, 25].

The mean score of SNR 50% for the WIN test in children with UHL after rehabilitation intervention for lists 1 (p=0.002) and 2 (p=0.005) was lower than the mean score before the intervention. Results showed significant improvement in children after training sessions. The decrease in the WIN test score reflects the individual's ability to selectively attend to a single ear and to listen in the presence of competitive noise. The results of the present study are consistent with the findings of Katz and Cohen. They found that practicing speech in the presence

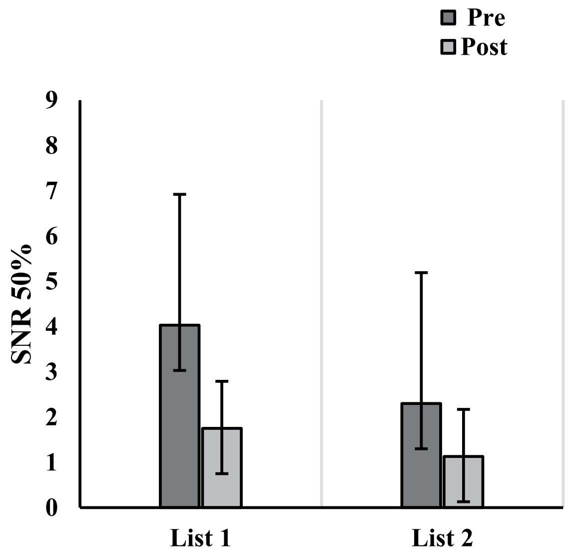

Figure 1. The average pre-training and post-training test scores of the words in the noise test in units of signal to noise ratio 50% (dB) for lists 1 and 2. SNR 50%; signal-to-noise ratio 50%

of noise can support listening in challenging noise environments [26]. The study by Zhang et al. showed that after training, the experimental group showed improvement in word and sentence recognition of noise. Study participants were children who used cochlear implants or hearing aids with unilateral hearing loss. Our findings are consistent with these results [23]. The Masters et al. study also showed an improvement in the ability to understand speech in the presence of noise in children who received speech rehabilitation intervention in the presence of noise [27].

One of the important findings of the CAEPs test in the presence of noise is the reduction of latency N1 and P2 waves recorded from the Fz electrode, and N1 wave recorded from the Pz electrode after rehabilitation exercises

($p<0.05$), indicating the effect of rehabilitation exercises and improvement of speech comprehension in noise. In general, neural plasticity resulting from speech comprehension and learning exercises can be sought through the involvement of different levels of auditory pathways and increased neural activity and communication [28]. The results of recent studies have clearly shown that the latency changes in the CAEP test can refer to the plasticity of the auditory system and the recovery of hearing loss, including cochlear implantation [29]. Therefore, la-

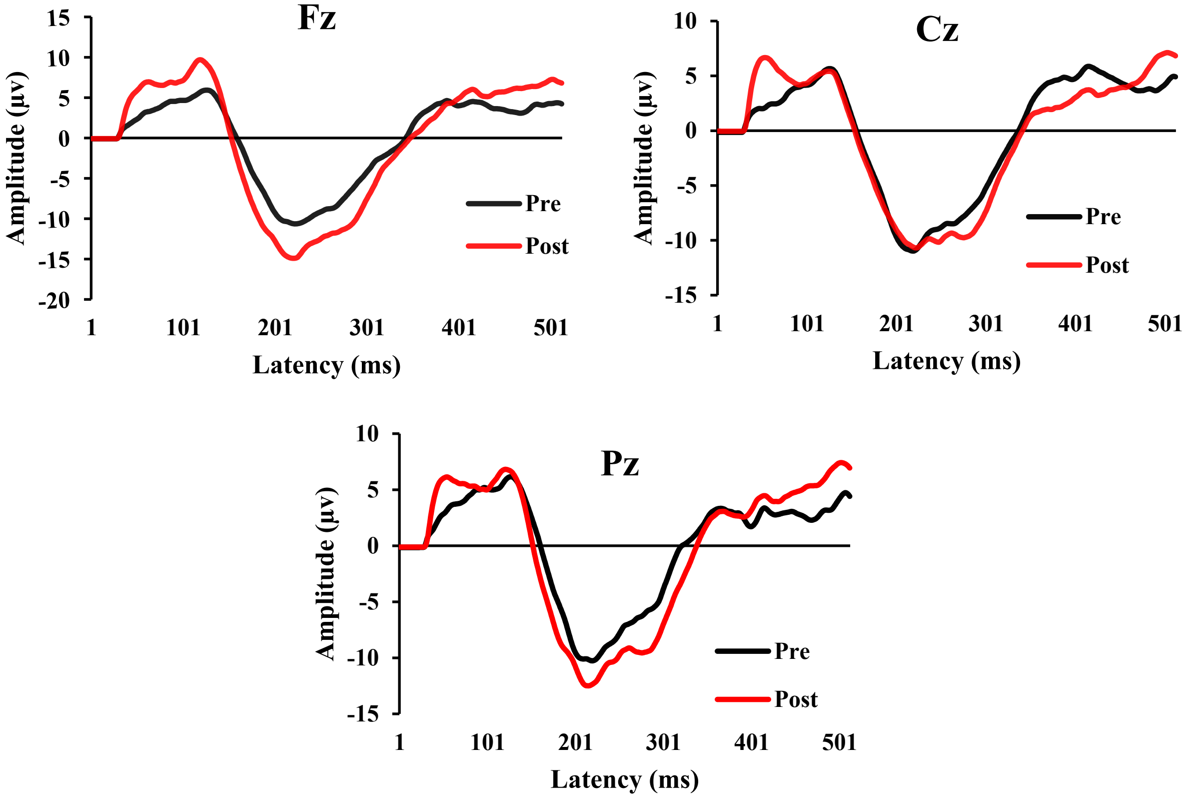

Figure 2. Grand average of cortical auditory evoked potentials waveforms elicited to /da/ in noise are shown for the electrode sites Fz, Cz, and Pz

tency reduction can result from the growth and development of cortical surface processes, including detection, differentiation, and increasing cortical plasticity [30]. On the other hand, the nature of speech perception exercises in noise is to reduce the sensitivity to noise and increase the power of these cortical surface processes [11].

Other findings related to the CAEPs test are significant changes in the amplitude of the recorded all waves from the Fz electrode, the P1 wave from the Cz electrode, and the P1 and N2 waves from the Pz electrode which indicate an increase in the amplitude after rehabilitation exercises ($p<0.05$). To evaluate the reasons for the rise in the amplitude of the recorded waves after rehabilitation, two important factors must be considered. First, noise affects the hemispheres of the brain in a different way than silence, a finding obtained by a cortical test recorded with a speech stimulus [31]. In addition, it seems that the response of the waves is caused at least in part by bilateral activity in the supratemporal plates. Thus, the increase in the amplitude of the waves recorded in the noise after rehabilitation exercises are related to the changes in the relative share of each hemisphere in response to the speech sound in noise. Other possible factors include increased synaptic strength, existing excitatory synapses, increased myelin axon levels of neurons, or the presence of more neurons in areas related to the response [28].

In various studies, increasing amplitude and decreasing latency has been reported as the effect of rehabilitation on cortical test components [32, 33]. The results of a study by Jutras et al., conducted on children with hearing impairment, showed increased amplitude and decreased latency of P1 and N2 waves after rehabilitation exercises [24].

Another objective of this study was to determine the correlation between the amplitude and latency of cortical response waves and WIN test score, which was not found to be significantly related ($p> 0.05$). This finding is consistent with the previous study [34]. There seems to be no significant relationship between these two tests, possibly due to different sources and a small number of samples. Because the WIN test is a behavioral test and requires more child participation, it involves more and higher areas at the cortical levels [35, 36]. However, the CAEPs test also affects the lower cortical levels, especially since these levels continue to grow and mature with age [37]. Another important factor in the lack of significant correlation is the small sample size. It seems that by changing the parameters involved in the CAEPs test and changes in the age range and the number of participants, a significant relationship can be achieved between these two tests.

Conclusion

The results showed that children’s ability to perceive speech in noise improved after training sessions. One of the most important points was to increase this ability during the training sessions and to have a greater tolerance to noise. These results suggest that rehabilitation exercises such as words-in-noise can be useful for children with unilateral hearing loss (UHL) since one of the most important problems of these people is speech perception in noise. Because the results in the present study are based on the performance of 13 participants with UHL, they should not be generalized to the wider population of children with UHL. Although there was no control group in this study, due to the close control over the cases and their monitoring in order not to influence the possible variables of the intervention, we tried to see only the effect of the intervention in the end. In future studies, using a larger control group may give us a more comprehensive picture of the training influences.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the ethics committee of TUMS under the code of IR.TUMS.FNM.REC.1400.082.

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Authors' contributions

MK: Collecting and analysis the data and writing the original manuscript draft; NR: Supervising, designing and developing the study and editing the manuscript; FF: Data mining and analysis; NY: Conducting ENT tests and referring participants; MY: Help with statistical data analysis; SA: Helping to develop the cortical recording protocol and signal analysis.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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