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Evaluation of the Effect of Musical Perception Activities on Speech Perception in Adult Cochlear Implant Users

Original Investigation

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Abstract

Objective: This study aimed to evaluate clinical musical perception, analyze the relationship between speech recognition and music perception, and investigate the effects of a three-month musical perception activities on these parameters in adult cochlear implant (CI) users with post-lingual hearing loss.

Methods: Free-field hearing and speech tests in a quiet environment, the Turkish matrix test, and the Turkish version of the clinical assessment of musical perception test were performed on 18 adult unilateral CI users before and after the three-month music training. Results were compared with those of 18 healthy controls.

Results: Prior to the musical perception activities, word recognition scores, Turkish matrix test results, and 500, 1000, and 6000 Hz free-field hearing thresholds were significantly correlated with the clinical assessment of musical perception test scores in the CI group ($p<0.047$). Timbre recognition scores ($p=0.019$) had improved significantly in the CI group after the three-month musical perception activities. On the other hand, timbre recognition scores had significantly affected the Turkish matrix test results (R^2adjusted=0.56).

Conclusion: Our study showed that speech perception in noise and clinical musical perception measurements affected each other in CI users. The inclusion of musical perception activities to support an auditory rehabilitation program may contribute to increased speech recognition skills in noise.

Keywords: Cochlear implantation, speech perception, music, pitch discrimination, timbre perception

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Introduction

Cochlear implants (CI) transmit acoustic signals to the cochlea and the central auditory system by transforming the signals into electrical stimuli. Like other devices developed to compensate for hearing loss, CI are primarily designed to convey speech sounds comfortably and effectively to the listener. Many factors affect the level of benefit obtained from CI in individuals with post-lingual hearing loss (1). Despite significant advances in speech perception, fundamental aspects of music perception remain a challenge for most CI recipients.

Music can be divided into several basic components: rhythm, pitch, melody, and timbre. It has been previously reported that CI users typically exhibited good rhythm perception but have poorer perception of pitch, melody, and timbre (2). Many tests have been described in the literature that measure the ability of CI recipients to perceive music (3). The University of Washington clinical assessment of music perception test (CAMP) was developed in 2009, and subsequently, the Turkish cross-cultural adaptation of the CAMP test was devised (4-6). The CAMP test evaluates pitch direction discrimination thresholds (PDD, dB) and standard errors for 262, 330, and 392 Hz base frequencies; melody recognition (MR, %); and timbre recognition (TR, %) scores. CAMP results of post-lingual adult CI recipients have been reported in previous studies (4, 7, 8). Pitch, timbre, and melody perception are high-level skills that reflect peripheral and central auditory system performance (8). Thus, the evaluation of such competencies in CI users can provide essential data regarding auditory reorganization after implantation. A significant relationship between musical perception and speech recognition has been reported in the literature (2, 9). This relationship reveals that better frequency resolution required for melody perception is also an important factor for speech recognition, especially in noise (10). Similarly, other studies have shown positive correlation between pitch perception and speech comprehension in noise (11, 12). It has been suggested that this could be due to the inability of CI users to distinguish between stimulus and noise because of pitch detection inadequacies (11). It has also been stated that a lack of musical perception could be due to a similar mechanism (13). Moreover, the findings of these previous studies suggest that musical perception activities (MPA) in CI users improved recognition of consonants in fluctuant noise, speech perception in noise, familiar MR, timbre identification, and musical pitch perception (12, 14, 15). MPA was also reported to lead to significant improvements in the perception of music and speech when applied for 45 minutes a day for three to five weeks (16).

While the relationship between speech recognition and musical perception in different populations have been evaluated in previous studies, this relationship, and the effect of MPA on speech recognition have not yet been studied in Turkish adult CI users. Therefore, in our study we aimed to evaluate clinical musical perception, analyze the relationship between speech recognition and musical perception in quiet and noise in comparison to healthy controls, and investigate the effects of three-month MPA on these parameters in adult monaural CI users with post-lingual hearing loss.

Methods

Ethical approval was obtained from the Göztepe Training and Research Hospital, Clinical Researches Ethics Committee (date: 10.04.2018, decision no: 2018/0092). In addition, this study was supported by the scientific research projects committee of the university (T_GAP_2019_1510).

Participants

Adult volunteers were recruited for the study. Eighteen post-lingually deafened unilateral CI users and 18 healthy adults were enrolled. CI users that met the following inclusion criteria were included in the CI group: aged 18–65 years at the time of testing, severe to profound post-lingual hearing loss, at least one year of unilateral CI use, normal auditory nerve and cochlear anatomy, mental competency to perform audiological and musical perception tests, no physical or psychological illness that could affect participation in the test, and ability to communicate verbally. Thirteen subjects had Opus2 sound processor (MedEl, Innsbruck, Austria) and used fine structure processing coding strategies; three subjects had Nucleus 6 processor, and one had a Kanso sound processor (Cochlear, North Sydney, Australia), both with advanced combination encoder coding strategies; and one subject had a Neuro 2 sound processor (Oticon Medical, Vallauris, France) with adaptive processing strategies. None of the CI users had formal musical education nor were they professional musicians; the participants were questioned regarding their usual music listening habits, and none listened to music regularly. Written informed consent was obtained from all participants.

Testing Procedure

Free-field behavioral hearing thresholds for 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz were obtained with frequency-modulated stimuli presented at a distance of 1 m and 0º azimuth using a Madsen Astera audiometer (Otometrics, Natus Medical, Denmark). Initially, the averages of the hearing thresholds were calculated for 500, 1000, 2000, and 4000 Hz. Then, speech detection thresholds (SDT), word recognition scores (WRS), and the most comfortable levels (MCL) in quiet were determined with the same setting. Next, the Turkish matrix test (TURMatrix), adapted for the Turkish language by Zokoll et al. (17) was performed to evaluate speech perception in noise performance of the patients in free field (Oldenburg Measurement Applications, HörTech, Oldenburg, Germany).

TURMatrix is a Turkish adaptive speech perception in noise test used to determine the threshold for speech recognition in the ±1 dB range. TURMatrix uses syntactically fixed sentences comprising five words: name, number, adjective, object, and verb. The test lists are randomly selected from a 50-word inventory, and 20 sentences are created using these words. Patients were asked to listen carefully and repeat the sentence in the presence of background noise. For each sentence, words known by the listeners were selected from the computer screen by the examiner. The scores were calculated as signal-to-noise threshold levels (dBSNR), where the listeners could correctly repeat more than 50% of the words. Speech stimuli were presented from 0°, and continuous 65 dBSPL bubble noise was presented from 180° azimuth (18). Before the test, all subjects performed a training session (17). In case of fatigue, all subjects were allowed short breaks.

Finally, the Turkish version of the clinical assessment of music perception test (CAMP-TR) evaluated CI recipients' pitch, timbre, and melody perception skills (5). The CAMP-TR test consists of three subtests that evaluate PDD, MR, and TR. CAMP-TR tests were conducted in a sound-treated double-walled room with a custom MATLAB (The MathWorks Inc., USA) program on a computer connected to a Madsen Astera audiometer (Otometrics, Natus Medical, Denmark) with a sound field presentation level of 65 dB-A. All stimuli were delivered through a JBL control one loudspeaker (JBL, Harman International, USA) positioned at 0° azimuth and 0° elevation at 1 m distance from the subjects. CAMP-TR testing was carried out following the procedure previously described by Nimmons et al. (19) and Yüksel and Çiprut (6).

After completing the first evaluation protocol, as daily MPA, participants were given a list of the instruments (Turkish saz, piano, guitar, violin, trumpet, flute, clarinet, and saxophone) and YouTube addresses of the melodies of CAMP-TR test (Appendix). Patients were free to choose the YouTube addresses where they would listen to the instruments in the CAMP-TR test. Patients were asked to listen to the melodies from the YouTube addresses (Appendix). The songs in the melody list were selected from the melodies in the MR subtest of the CAMP-TR test. There were no predetermined acoustic targets. Care was taken to ensure that the selected songs were not polyphonic or symphonic. Support was obtained from the family members of those participants who had insufficient internet usage skills. The patients were given a music listening diary and were asked to listen to the melodies and the instruments for 45 minutes per day (either in one go or in three 15-minute sessions) and mark their listening on the checklist. The MPA period continued for three months, and then the CI group was reevaluated with the same testing protocol, and the results were analyzed.

Statistical Analysis

The power of this study was calculated based on a reference study using G* Power version 3.1.9.2 (6). Assuming a medium effect size value of 0.50, a total of 36 participants were estimated to be sufficient with 80% power at a 95% confidence level. Distribution of the data was analyzed using the Shapiro–Wilk test. As the data distribution was not normal, nonparametric tests were performed for statistical analyses. Continuous data median, minimum and maximum values, and frequencies of categoric data were calculated. In addition, to analyze the significance of differences between independent and related groups before and after the three-month MPA, Mann–Whitney U and Wilcoxon signed-rank tests were performed. Relationships between the continuous variables were analyzed by calculating the Spearman's correlation coefficients. Multiple regression analysis was done to study the relationships between parameters in the CI group. Four multiple regression models were created to analyze the relationship between the CI group findings. The first model evaluated the effect of independent variables of pitch, melody, and timbre discrimination percentages on the TURMatrix test signal-to-noise ratios dependent variable. The second model evaluated the effect of the average of free-field hearing thresholds, SDT, WRS and most comfortable loudness levels independent variables on TURMatrix test signal-to-noise ratios dependent variable. The third model evaluated how the independent variables of the averages of free-field hearing thresholds, SDT, and most comfortable loudness levels affected the dependent variable of the WRS. The fourth model evaluated how much the independent variables of 250–8000 Hz free field hearing thresholds affected the WRS dependent variable. Statistical analysis was performed using SPSS 21.0 (SPSS Inc., IBM, New York, USA). A p-value less than 0.05 was considered significant for all tests.

Results

The study included 36 participants, namely, 13 males (72.2%) and 5 females (27.8%) in the CI group, and 11 males (61.1%) and 7 females (38.9%) in the control group. Of the participants in the CI group, 11 (61.1%) had CI in the right ear and 7 (38.9%) in the left ear. The median age was 31 years in the CI group, with a minimum of 19 and a maximum of 65 years. In the control group, the median age was 34 years, with a minimum of 22 and a maximum of 65 years. There was no significant age difference between the groups ($p=0.924$). The median duration of CI usage was 45.5 months, with a minimum of 12 and a maximum of 192 months, and the duration until implantation (time from diagnosis of hearing loss to cochlear implantation, patients used hearing aid/s unilaterally or bilaterally) was 32 years with a minimum of 15 and a maximum of 59 years (Table 1). The CI group's free-field hearing and speech test results in quiet were significantly worse than those of the control group ($p<0.001$) (Table 2). TURMatrix, PDD, MR, and TR scores were also significantly lower in the CI group than in the controls ($p<0.001$) (Table 3). It was determined that the TR scores ($p=0.019$) improved significantly in the CI group after three months of MPA (Tables 2, 3).

Four multiple regression models were created to analyze the relationship between the CI group findings (Table 4). The first model evaluated the effects of independent variables (pitch, melody, and timbre discrimination percentages before MPA) on the dependent variable (TURMatrix test signal-to-noise ratios before MPA). As a result of the analysis, a significant regression model could be formed [F(8,9)=3.697, p=0.034] and it was found that 56% of the variance in the dependent variable (R^2adjusted =0.559) was affected by the independent variables. The timbre perception negatively and significantly affected the signal-to-noise ratios [β=-0.568, t(9)=-3.264, p=0.01, pr^2=0.542]. It was determined that other independent variables did not affect the dependent variable significantly. The second model evaluated the effects of the independent variables (averages of free-field hearing thresholds, SDT, WRS and most comfortable loudness levels after MPA) on the dependent variable (TURMatrix test signal-to-noise ratios after MPA). As a result of the analysis, a significant regression model could be established [F(4,12)=7.907, p=0.002], and it was found that 63% of the variance in the dependent variable (R^2adjusted =0.633) was affected by the independent variables. Accordingly, the WRS [β=-0.855, t(12)=-4.228, p=0.001, pr^2=0.599] have negative and significant effects on the TURMatrix test signal-to-noise ratios. It was determined that other independent variables did not affect the dependent variable significantly. The third model evaluated how much the independent variables of the averages of free-field hearing thresholds, SDT, and most comfortable loudness levels (before MPA) affected the dependent variable of WRS (before MPA). As a result of the analysis, a significant regression model could be created [F(3,14)=4.802, p=0.017] and it was found that 40% of the variance in the dependent variable (R^2adjusted =0.402) was affected by the independent variables. Accordingly, the most comfortable loudness levels affected the WRS negatively and significantly [β=-0.545, t(12)=-2.331, p=0.035, pr^2=0.279]. It was found that other independent variables did not affect the dependent variable significantly. The fourth model evaluated how much the independent variables of 250–8000 Hz free field hearing thresholds (after MPA) affected the dependent variable of WRS (after MPA). As a result of the analysis, a significant regression model could be created [F(7,9)=3.368, p=0.047] and it was found that 51% of the variance in the dependent variable (R^2adjusted =0.509) was affected by the independent variables. Accordingly, 250 Hz [β=-0.885, t(9)=-2.402, p=0.04, pr^2=0.391] and 6000 Hz free-field hearing thresholds [β=-1.136, t(9)=-2.285, p=0.048, pr^2=0.367] affected the WRS negatively and significantly. It was determined that other independent variables did not affect the dependent variable significantly.

Table 1. Demographics of study and control groups

	CI group	Controls
n	13 males 5 females	11 males 7 females
Age (years)	31 (min: 19, max: 65)	34 (min: 22, max: 65)
Duration of CI use (months)	45.5 (min: 12, max: 192)	-
Duration until implantation (years)	32 (min: 15, max: 59)	-
CI ear	11 right ears, 7 left ears	

CI: Cochlear implant, min: Minimum, max: Maximum

Relationships between the test parameters before the MPA were analyzed with Spearman's correlation coefficients (Tables 5-7, Figure 1). Accordingly, before MPAs were held, WRS, MCL, TURMatrix (dBSNR), and the 500, 1000, and 6000 Hz free-field hearing thresholds were significantly correlated with the CAMP-TR scores in the CI group (p>0.047). Before the MPA, the 1000 Hz free-field hearing

Table 2. Free-field hearing and speech tests findings in quiet, and comparisons of CI group and controls

Test parameters	Pre-tests of CI group			Post-tests of CI group			Controls			Controls versus post-tests of CI group (Mann–Whitney U)		Pre versus post-tests of CI group (Wilcoxon signed-ranks)	
	Median	Min	Max	Median	Min	Max	Median	Min	Max	p	z	p	z
250 Hz	30	20	60	30	20	60	10	0	15	<0.001	-5.094	0.414	-0.816
500 Hz	35	25	55	35	25	55	7.5	0	15	<0.001	-5.101	1	0.000
1000 Hz	35	25	50	35	25	50	7.5	0	20	<0.001	-5.089	0.518	-0.647
2000 Hz	35	10	45	35	10	45	5	0	15	<0.001	-4.893	0.234	-1.190
4000 Hz	32.5	10	45	30	10	50	5	5	20	<0.001	-4.94	0.276	-1.089
6000 Hz	35	20	50	35	20	55	10	0	20	<0.001	-5.08	0.071	-1.807
8000 Hz	35	25	60	40	25	65	7.5	0	25	<0.001	-5.043	0.197	-1.289
Averages of 500–4000 Hz (dB)	34	18	48	32	18	50	8	2	18	<0.001	-5.049	0.553	-0.594
Speech detection thresholds (dB)	37.5	25	60	35	25	55	15	5	25	<0.001	-5.033	0.317	-1
Word recognition scores (%)	48	4	80	44	4	80	96	92	100	<0.001	-5.104	0.071	-1.983

Pre: Before musical perception activities, Post: After musical perception activities, CI: Cochlear implant, min: Minimum, max: Maximum

Table 3. Results of Turkish Matrix and Turkish version of clinical assessment of music perception tests in CI group and controls

Test parameters	Pre-tests of CI group			Post-tests of CI group			Controls			Controls versus post-tests of CI group (Mann–Whitney U)		Pre versus post-tests of CI group (Wilcoxon signed- ranks)	
	Median	Min	Max	Median	Min	Max	Median	Min	Max	p	z	p	z
TurMatrix (dBSNR)	22.5	4	23	22.5	4.8	25	-3.45	-7.7	2.8	<0.001	-5.059	0.286	-1.067
Pitch discrimination (262 Hz-thresholds)	5.28	0.94	11.94	5.28	2.72	11.94	2.41	0.78	11	<0.001	-3.516	0.646	-0.459
Pitch discrimination (262 Hz-standard errors)	1.34	0.07	3.54	2.01	0.07	4.42	0.55	0.07	2.14	0.007	-2.658	0.328	-0.978
Pitch discrimination (330 Hz-thresholds)	6.77	1.72	11.5	7.11	0.83	11.56	2	0.72	11.5	<0.001	-3.518	0.248	-1.156
Pitch discrimination (330 Hz-standard errors)	1.85	0	4.14	1.29	0	3.5	0.34	0.14	2.69	0.057	-1.899	0.79	-0.267
Pitch discrimination (391 Hz-thresholds)	3.91	1	11.39	4.22	1.28	11.56	0.88	0.61	1.78	<0.001	-4.792	0.683	-0.408
Pitch discrimination (391 Hz-standard errors)	1.68	0.07	4.26	1.6	0.07	4.26	0.28	0.07	1.18	0.001	-3.221	0.173	-1.364
Melody recognition (%)	6.94	0	55.56	8.33	0	55.56	76.39	12.5	91.67	<0.001	-4.548	0.496	-0.680
Timbre recognition (%)	10.41	4.17	45.83	16.67	4.17	50	77.08	12.5	95.83	<0.001	-4.634	0.019	-2.346

Pre: Before musical perception activities, Post: After musical perception activities, CI: Cochlear implant, min: Minimum, max: Maximum, TURMatrix: Turkish matrix test

thresholds were significantly correlated with the duration of CI use (p=0.04). TURMatrix showed a significant relationship with the 500 Hz free-field hearing thresholds (p=0.022), SDT (p=0.035), WRS (p<0.001), MR (p=0.03), and PDD standard errors (p<0.032) (Table 5). After the MPA, the TURMatrix was significantly correlated with the 250 and 500 Hz free-field hearing thresholds, post-WRS, post-TR, and post-MR scores (p<0.04). PDD scores were correlated with the pre-WRS, pre-TURMatrix, and post-1000–6000 Hz free-field hearing thresholds (p<0.049). TR scores were correlated with pre-WRS, post-1000, and 6000 Hz free-field hearing thresholds and post-WRS (p<0.027). MR scores were significantly correlated with age, the duration before CI, the 500 Hz free-field hearing thresholds, and post-MCL (p<0.0049) (Table 6). In the control group, age was significantly correlated with SDT, MCL, TURMatrix, and TR (p<0.049). TURMatrix exhibited a relationship with speech audiometry parameters and 391 Hz PDD scores (p<0.037) (Table 7). PDD and MR scores showed significant correlation with 1000 and 4000 Hz free-field hearing thresholds (p<0.049), and TR scores also exhibited relationships with 6000 and 8000 Hz thresholds (p<0.038) (Table 7). Parameters that present change in correlation before and after MPA in the CI group.

Discussion

In the literature, tests such as speech recognition in quiet or noisy environments, hearing thresholds measurements, and analysis of changes in temporal auditory processing have been used to evaluate auditory performance after CI (8, 19-22). Perceptions of pitch, timbre, and melody are high-level skills, which can reflect the performance of the peripheral and central auditory systems (8, 9, 13, 23). Therefore, the assessment of such abilities in patients can provide significant data regarding auditory reorganization after cochlear implantation.

CAMP findings of adult CI users have been previously reported. Kang et al. (4) reported the PDD score averages of post-lingual adult CI recipients as 2.9±2.7, 3.4±3.1, and 2.5±2.5 for 262, 330, and 392 Hz base frequencies, respectively, and MR and TR as 25.1±22.2% and 45.3±16.2%, respectively. The best performance in the PDD scores was seen at 391 Hz base frequency, while the worst was at 330 Hz. Similarly, the base frequencies that presented the best and worst performances in our study were 391 and 330 Hz, respectively. In another study, Jung et al. (7) reported PDD score averages of 2.7±1.7 st, 4.4±4.2 st, and 8.1±3.0 st for 262, 330, and 391 Hz base frequencies, respectively, and MR and TR as 21.1±21.7% and 25.7±8.5%, respectively. Drennan et al. (8) reported PDD score averages as 3.15 st, 2.59 st, and 3.11 st for 262, 330, and 392 Hz base frequencies, and MR and TR were 26.2 and 43.2%, respectively. The CAMP results reported by other researchers are better than those obtained in our study. This may be related to differences in CI use (monaural, binaural, or bimodal), sample size, duration of CI use, and heterogeneous musical background.

Table 4. Summary of the multiple regression models

Models	Dependent variable	Independent variables	Adjusted R square	df1	df2	F	Sig.	Independent variables affect dependent variable	Beta	t(df2)	Sig.	pr^2
1	TurMatrix (S/N) ratios (before musical perception activities)	262, 330 and 391 Hz pitch perception thresholds, melody, and timbre discrimination percentages (before musical perception activities)	0.559	8	9	3.697	0.034	Timbre discrimination percentages	-0.568	-3.264	0.01	0.542
2	TurMatrix (S/N) ratios (after musical perception activities)	Average of free-field hearing thresholds, speech detection thresholds, word recognition scores and most comfortable loudness levels (after musical perception activities)	0.633	4	12	7.907	0.002	Word recognition scores	-0.855	-4.228	0.001	0.599
3	Word recognition scores (before musical perception activities)	Averages of free-field hearing thresholds, speech detection thresholds, and most comfortable loudness levels	0.402	3	14	4.802	0.017	Most comfortable loudness levels	-0.545	-2.331	0.035	0.279
4	Word recognition scores (after musical perception activities)	250–8000 Hz free field hearing thresholds (after musical perception activities)	0.509	7	9	3.368	0.047	250 Hz free field hearing thresholds	-0.885	-2.402	0.04	0.391
								6000 Hz free field hearing thresholds	-1.136	-2.285	0.048	0.367

TURMatrix: Turkish matrix test

Table 5. Correlation coefficients between test parameters before musical perception activities in CI group

	Spearman's correlation coefficients	Duration of implantation	Pre-TURMatrix	Pre-PDD thresholds			Pre-PDD standard errors			Pre-TR	Pre-MR
				262 Hz	330 Hz	391 Hz	262 Hz	330 Hz	391 Hz		
Pre 500 Hz	r	-	0.537*	-	-	0.473*	-	-	-	-	-0.582*
	p	-	0.022	-	-	0.047	-	-	-	-	0.011
Pre 1000 Hz	r	-0.487*	-	-	-	-	-	-	-	-	-0.551*
	p	0.04	-	-	-	-	-	-	-	-	0.022
Pre 6000 Hz	r	-	-	-	-	-	-	-	-	0.503*	-
	p	-	-	-	-	-	-	-	-	0.033	-
Pre SDT	r	-	-0.498*	-	-	-	-	-	-	-	-
	p	-	0.035	-	-	-	-	-	-	-	-
Pre WRS	r	-	-0.742**	-	-0.471*	-	-	-	-	-	0.525*
	p	-	<0.001	-	0.049	-	-	-	-	-	0.025
Pre MCL	r	-	-	-	0.544*	-	-	-	-	-	-0.603**
	p	-	-	-	0.02	-	-	-	-	-	0.008
Pre-TURMatrix	r	-	-	-	-	-	-	0.509*	0.586*	-	-0.512*
	p	-	-	-	-	-	-	0.031	0.011	-	0.03

*Moderate correlation, **Strong correlation, Pre: Before musical perception activities, SDT: Speech detection thresholds, WRS: Word recognition scores, PDD: Pitch direction discrimination, TR: Timbre recognition, MR: Melody recognition, MCL: Most comfortable level, CI: Cochlear implant, CAMP-TR: The Turkish version of clinical assessment of music perception test, TURMatrix: Turkish matrix test

Table 6. Correlation coefficients between test parameters after musical perception activities in CI group

	Spearman's correlation coefficients	Post-PDD thresholds						
		262 Hz	330 Hz	391 Hz	Post-TR	Post-MR	Post-WRS	Post-TURMatrix
Age	r	-	-	-	-	-0.551*	-	-
	p	-	-	-	-	0.022	-	-
The duration before CI	r	-	-	-	-	-0.486*	-	-
	p	-	-	-	-	0.048	-	-
Pre WRS	r	0.484*	-	-	0.553*	-	-	-
	p	0.019	-	-	0.021	-	-	-
Pre TURMatrix	r	-	-	0.568*	-	-	-	-
	p	-	-	0.014	-	-	-	-
Post 250 Hz	r	-	-	-	-	-	-0.634*	0.553*
	p	-	-	-	-	-	0.006	0.021
Post 500 Hz	r	-	-	-	-	-0.589*	-0.597*	0.612*
	p	-	-	-	-	0.013	0.011	0.009
Post 1000 Hz	r	0.571*	-	-	-0.538*	-	-0.588*	-
	p	0.004	-	-	0.026	-	0.013	-
Post 2000 Hz	r	-0.561*	-	-	-	-	-	-
	p	0.019	-	-	-	-	-	-
Post 4000 Hz	r	-0.715**	-	-	-	-	-	-
	p	0.001	-	-	-	-	-	-
Post 6000 Hz	r	-0.528*	-	0.512*	-0.543*	-	-0.498*	-
	p	0.029	-	0.036	0.024	-	0.042	-
Post averages of 500–4000 Hz (dB)	r	-0.486*	0.521*	-	-	-	-	-
	p	0.048	0.032	-	-	-	-	-
Post WRS	r	-	-	-	0.589*	-	-	-0.812**
	p	-	-	-	0.013	-	-	<0.001
Post MCL	r	-	-	-	-	-0.583*	-	-
	p	-	-	-	-	0.014	-	-
Post-TURMatrix	r	-	-	-	-0.505*	-0.505*	-0.812**	1
	p	-	-	-	0.039	0.039	<0.001	1

*Moderate correlation, **Strong correlation, Pre: Before musical perception activities, Post: After musical perception activities, WRS: Word recognition scores, PDD: Pitch direction discrimination, TR: Timbre recognition, MR: Melody recognition, MCL: Most comfortable level, CI: Cochlear implant, CAMP-TR: The Turkish version of clinical assessment of music perception test, TURMatrix: Turkish matrix test

In the literature, the definition given for pitch discrimination ranges from the ability to hear a semitone difference up to a difference of two octaves. The ability to hear rhythm and duration in CI users is close to normal. Timbre perception is generally poor, but about two-thirds of listeners can identify instruments in a closed set. CI recipients typically have poor melody perception but are supported by rhythm and lyrics. Without rhythm or lyrics, only about a third of those with implant can identify common melodies in a closed set. Correlations were found between the ability to perceive music and speech perception in noisy environments. Therefore, improving music perception may provide further clinical benefits (21).

MR was reported as the most challenging parameter of musical perception for patients with CI, as the melody's frequency range affected CI MR, with higher frequency ranges producing better performances (10). Also in our study, MR was the test that patients had the most difficulty with. However, 500 Hz free-field hearing thresholds of both pre- and post-music training showed significant correlation with MR. Higher frequency hearing thresholds with CI did not show significant relationship with MR.

Positive correlation was reported in the literature between low-frequency hearing and pitch recognition, while negative correlation was observed between high-frequency hearing and pitch recognition (24). Similarly, in our study, 500 Hz free-field hearing thresholds were positively correlated with 391 Hz PDD thresholds, and 2, 4, and 6 kHz free-field hearing thresholds were negatively correlated with 262 Hz PDD thresholds.

Table 7. The correlation coefficients between test parameters in controls

	Spearman's correlation coefficients	SDT	MCL	TURMatrix	PDD thresholds			PDD standard errors			TR	MR
					262 Hz	330 Hz	391 Hz	262 Hz	330 Hz	391 Hz		
Age	r	0.559*	0.559*	0.604**	-	-	-	-	-	-	-0.469*	-
	p	0.016	0.016	0.008	-	-	-	-	-	-	0.049	-
1000 Hz	r	0.494*	-	-	-	-	-	-	-	0.473*	-	-0.582*
	p	0.037	-	-	-	-	-	-	-	0.048	-	0.011
4000 Hz	r	-	-	-	-	-	-	-	0.528*	-	-	-0.520*
	p	-	-	-	-	-	-	-	0.024	-	-	0.027
6000 Hz	r	-	-	-	-	-	-	-	-	-	-0.494*	-
	p	-	-	-	-	-	-	-	-	-	0.037	-
8000 Hz	r	-	-	-	-	-	-	-	-	-	-0.588*	-
	p	-	-	-	-	-	-	-	-	-	0.01	-
SDT	r	1	-	-0.623*	-	-	-	-	-	-	-	-
	p	1	-	0.006	-	-	-	-	-	-	-	-
WRS	r	-	-	-0.496*	-	-	-	-	-	-	-	-
	p	-	-	0.036	-	-	-	-	-	-	-	-
MCL	r	-	1	0.623**	-	-	-	-	-	-	-	-
	p	-	1	0.006	-	-	-	-	-	-	-	-
TURMatrix	r	-	-	1	-	-	0.568*	-	-	0.508*	-	-
	p	-	-	1	-	-	0.014	-	-	0.031	-	-

*Moderate correlation, **Strong correlation, SDT: Speech detection thresholds, WRS: Word recognition scores, PDD: Pitch direction discrimination, TR: Timbre recognition, MR: Melody recognition, MCL: Most comfortable level, CI: Cochlear implant, TURMatrix: Turkish matrix test

It has been stated that PDD, MR, and TR were significantly associated with word recognition and speech perception in noise (2, 4, 7, 10, 25). In our study, WRS correlated with 330 Hz PDD thresholds and MR scores before the MPA. In addition, TURMatrix dBSNR thresholds also showed significant correlation with 330 and 391 Hz PDD standard errors and MR scores. Following MPA, WRS showed correlation with TR scores, and TURMatrix dBSNR thresholds showed significant correlation with 391Hz PDD thresholds, TR, and MR scores.

Gfeller et al. (10) reported weak correlation between hearing loss history and pitch perception but found that hearing loss and implant duration had a significant effect on speech perception. In their study, the authors found negative correlation between the duration of implant use and pitch perception, while in another study, Gfeller et al. (9) described a weak relationship between the duration of CI use and musical pitch perception. In contrast, Jung et al. (7) reported no relationship between age, the duration of deafness or CI use, and musical perception, whereas Drennan et al. (8) reported negative correlation between age and timbre and weak correlation between melody perception and CI use. In our study, the ages of patients showed significantly negative correlation with MR scores. Also, the duration before CI showed significantly negative correlation with MR scores. It is estimated that the short duration of hearing aid usage, and the cochlear implantation as early as possible, may positively affect the MR ability.

Lo et al. (26) found that while six weeks of melodic listening training improved pitch perception, temporal processing, and consonant recognition in quiet in CI users, such training did not change speech recognition in noise. Another study found that one month of audiobook and music listening training improved pitch and timbre perception in adult CI users (15). Petersen et al. (27) suggested that music education and music listening studies, when started in the early postoperative period, were effective in improving speech perception; however, this effect might also be related to implant adaptation. There are also studies reporting that consonant recognition and perception of prosody improved after music education, but speech recognition in noise were not affected (28). Our study included patients who had been using CI for at least one year to eliminate the adaptation factor. After three months of MPA, we found that the TR scores (p=0.019) had improved significantly. However, WRS in quiet and speech recognition in noise remained unchanged.

The potential of CI speech processing strategies to affect music perception has also been evaluated in the literature. For example, it has been shown that the harmonic single sideband encoder strategy had potential advantages over continuous interleaved sampling or similar strategies in conveying timbre cues to CI recipients by encoding

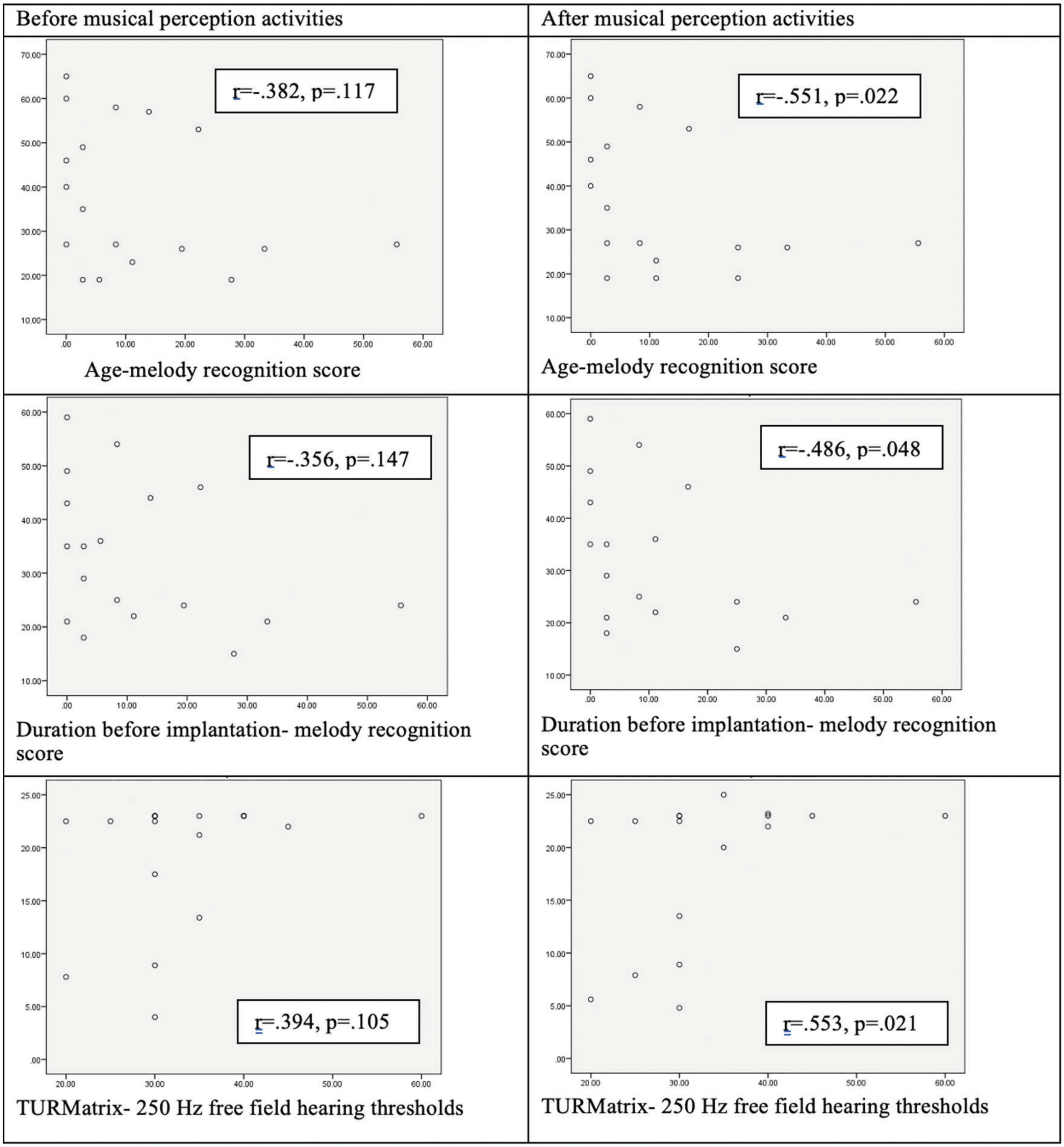

Figure 1. Parameters that present change in correlation before and after musical perception activities in the cochlear implant group
TURMatrix: Turkish matrix test

harmonic and temporal fine structure information (29). Further, Parkinson et al. (30) compared the MR and TR results of traditional electrical stimulus and electro-acoustic (hybrid) stimulus systems in CI recipients. Their results showed that hybrid system CI recipients performed better in MR, probably because of better low-frequency perception with acoustic stimuli. There were, however, no differences in the timbre discrimination test. Unfortunately, in our study, the sample size was insufficient to compare different speech processors or strategies.

The multiple regression analysis showed that the ability to perceive timbre, one of the clinical music perception parameters, affected speech recognition abilities in noise. This finding is not valid for the WRS in silence. This result strengthens the idea that music perception should be improved to increase speech recognition skills in CI users in their natural habitat.

The low number of subjects, the socio-cultural heterogeneity of the patients, the fact that patients living in a different city could not effectively continue their auditory rehabilitation programs after cochlear implantation, and that the patients, in general, did not have the habit of listening to music were the limitations of our study. In this study, MPA continued for three months. However, it is predicted that musical perceptional activities that started immediately after cochlear implantation and lasted longer could enable more significant changes in audiological evaluation parameters.

Conclusion

The inclusion of MPA to support an auditory rehabilitation program may contribute to increased speech recognition skills in noise. It is estimated that the increase in longitudinal studies evaluating musical perception in CI users would contribute to the literature.

Ethics Committee Approval: Ethical approval was obtained from the University of Health Sciences Turkey, Göztepe Training and Research Hospital, Clinical Research Ethics Committee (date: 10.04.2018, decision no: 2018/0092).

Informed Consent: Written informed consent was obtained from all participants.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept: B.M., M.T.T., M.Y., M.T.K., Design: B.M., M.T.T., M.T.K., Data Collection and/or Processing: B.M., M.T.T., Analysis and/or Interpretation: B.M., M.T.T., Literature Search: B.M., M.T.T., M.Y., Writing: B.M., M.T.T., M.Y., M.T.K.

Conflict of Interest: The authors have no conflicts of interest to declare.

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Main Points

- The ability to speech recognition in noise increases as the ability to timbre recognition increases.
- The ability to speech recognition in noise improves as melody recognition improves.
- Melody recognition skills show negative relationship with age of patients.

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Appendix
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2. https://www.youtube.com/watch?v=Dywhwm4Gstk Mutlu yıllar sana
3. https://www.youtube.com/watch?v=h_mokaAf6Nc&t=11s Benim annem güzel annem
4. https://www.youtube.com/watch?v=SbSaRT7x85I Yağmur yağıyor
5. https://www.youtube.com/watch?v=Fm-_tlLWv4A Dağ başını duman almış
6. https://www.youtube.com/watch?v=sJ4Ze3BcPk4 Baş parmağım neredesin
7. https://www.youtube.com/watch?v=njlgzg8nctM Bak postacı geliyor
8. https://www.youtube.com/watch?v=I5P4WCF5gWY Daha dün annemizin
9. https://www.youtube.com/watch?v=zfUEAK9tJ0M Mini bir kuş
10. https://www.youtube.com/watch?v=MnCQyemsFPA Küçük kurbağa
11. https://www.youtube.com/watch?v=kaGYK9RCfoI Kırmızı balık
11. https://www.youtube.com/watch?v=7WYDeCdIRQ8 Baltalar elimizde