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Auditive and Audiotactile Music Perception of Cochlear Implant Users

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Introduction

Cochlear Implants (CI) are medical prosthetics which enable the sense of hearing to children and adults with severe to profound hearing loss when current hearing aids can provide no benefit. Normal hearing aids can only amplify the sound input; conversely, cochlear implants bypass the damaged areas of the inner ear and stimulate directly electrically the auditory nerve. However, their technology is optimized for speech perception. Thus, while speech information is conveyed relatively accurately, musical signals cannot be perceived in detail. Technical limitations, as well as individual properties greatly influence the recognition, discrimination and consequently the enjoyment of music [1]. Temporal music cues, such as rhythm, beat or tempo are easily recognized. On the contrary, frequency associated tasks, such as timbre identification, pitch discrimination and melody recognition present a great challenge [1,2]. However, sound signals can be also perceived through vibrotactile stimulation [3-5]. Research results in the field of every day multimodal interactions indicate an important interplay between audio and vibrotactile inputs. The somatosensory and the auditory system are strongly correlated and stimuli of both modalities are integrated into one percept [5]. The study presented originated in these observations: It investigates the possibility of improving music perception of child implant users by presenting simultaneous vibrotactile during auditory stimulation. Therefore, an experiment with two listening tasks was conducted, one focusing on melody, and one on rhythm perception, which were both hypothesized to improve when musical vibrotactile stimulation is presented.

Experiment

Test System

For the vibrotactile stimulation a wooden chair was built which enabled the transmission of vibratory signals through two attached bass shakers: one under the seat and one behind the back of the chair. The experimental set-up consisted of this chair, one single external loudspeaker for the transmission of the audio signals positioned 1.2 m in front of participants, one stereo amplifier, and one touch-screen laptop where the children should report their answer (see Fig.1).

Stimuli

Both task (melody vs. rhythm perception) adapted the music test battery for Evaluation of Musical Abilities in childhood, developed at the University of Montreal (2013) [10]. The Battery (MBEMA) is freely accessible at: http://www.brans.umontreal.ca/short/mbea-child).
Each test is constituted of 20 melody-pairs either same or different (with either pitch or rhythmic variation in the second melody). Accordingly total, 40 pairs from the abbreviated version of the MBEMA were used. Those stimuli are computer-synthesized with an average duration of 3.5 sec per melody. All melodies are monophonic and composed following the tonal system of western music, in 10 different keys, played by 10 different midi instruments.

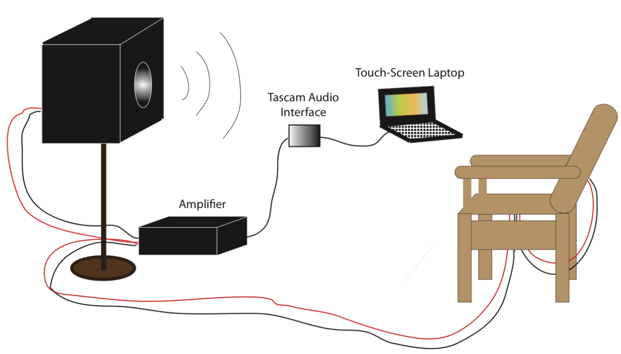

Figure 1: Test System.

Subjects

Seventeen prelingually deafened children and adolescents (10 female, age in years M=11.4, range=10.9) were recruited through the Cochlear Implant Center of Berlin-Brandenburg. The criteria of participation included bilateral implantation with more than 6 months experience. Because of the fact that most children were not simultaneously bilaterally implanted, the individual average value of the mean duration of CI-experience for the right and the left side was calculated (group mean = 7 years). All subjects attended ordinary schools and were able to communicate verbally. The degree of hearing capacity was determined by the most recent individual audiometric test data. These values represent the mean hearing thresholds (dB) for the frequency range between 250 Hz and 8 kHz (mean in dB = 22.5). The etiology of deafness was unknown for the most of the children. All participants used Nucleus 24 Contour Implants with CP810, CP910 and Freedom Sound Processors.

Procedure

The study was conducted at the Cochlear Implant Center of Berlin-Brandenburg. All participants were tested in individual session and used their own processors without making any changes. For the vibrotactile stimulation the original music recordings were transposed 2 octaves lower, synchronized, and bounced into one stereo signal with their corresponding originals (using a MATLAB algorithm). The resulting stimuli were subsequently RMS normalized in real time, low-pass-filtered with a second order Butterworth filter (Cut-off frequency at 250 Hz), and presented in parallel to the auditory loudspeaker stimulation. The frequency range of the test stimuli extended between (from B1=61.74 Hz to B3=246.9 Hz for the vibrotactile stimuli and from B3 to B5=987.7 Hz for the audio stimuli with A=440 Hz).

In each trial the first melody was played followed by a 2 sec. silence and then the second comparison melody was presented. All trials were answered in a same/different (yes/no) forced-choice paradigm. Using a within-subjects design, all participants conducted both tasks (rhythm vs. melody variation) under audio-only and audiovibrotactile stimulation in random order.

Results

As illustrated by Figure 2, there was an increase in correct response probability (Hit Rate) during the additional vibrotactile stimulation. Furthermore, the rhythm task was easier than the melody task. Both main effects (stimulation and task type) were significant fixed effect predictors in a Generalized Linear Model (see Table 1).

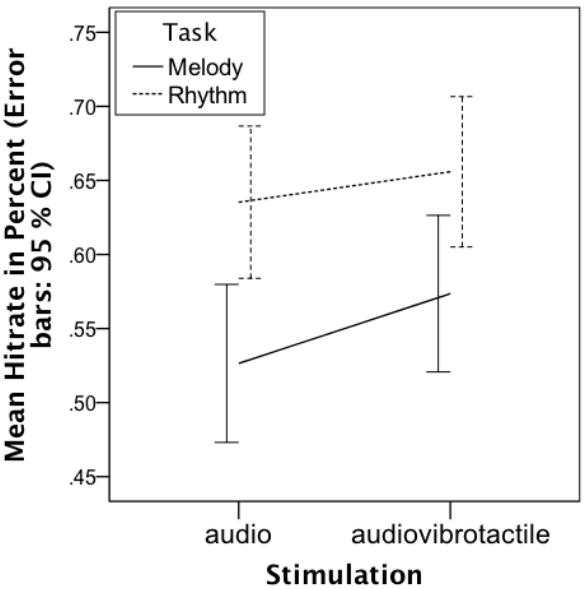

Figure 2: Mean Performance of Hit Rate in percent for Melody and Rhythm Tasks under both experimental conditions.

Even though Figure 2 indicates that the vibrotactile stimulation was more effective in the melody perception task, there was no was significant interaction effect in this analysis.

Table 1: Fixed Effects *b*-Coefficients from Generalized Linear Modeling of Hit Rate

Model Term	*b*	*SE*	*t*	*p*
Intercept	.07	.07	.95	.34
Audiovibrotactile Stimulation[1]	$.12^{*}$	.06	2.02	.04
Rhythm Task[2]	$.28^{***}$	.07	3.80	<.001
Audiovibrotactile Stimulation*Rhythm Task	-.06	.09	-.74	.45

Note: Dummy coding: [1]audio only stimulation as reference category; [2]melody task as reference category; The following model configuration based on AIC and BIC criteria provided the best fit: Binomial probability distribution; Link function: Probit, Repeated effects residual covariance structure: Compound Symmetry; $^{*}p<.05$ $^{***}p<.001$.

Discussion and Conclusions

As expected, rhythm perception accuracy with CIs was higher compared to the pitch perception performance [1, 2, 8]. Furthermore, results show that the vibrotactile stimulation significantly improved both the melody and the rhythm recognition rate of child implant users, confirming the hypothesis that sound vibrations are able to enhance musical experience of congenitally deafened children.

However, the effect of the vibrotactile stimulation on the recognition rate of the child CI-users was small (5-10%). Still, pitch perception through CIs remains a challenging factor and most of the children reported great recognition difficulties during the melody test. This fact may reflect the interplay of several factors.

Technical characteristics such as processing algorithms, device model, electrode activation and configuration could affect the recognition and discrimination capacity of cochlear implant users [1,8]. For the future studies two more parameters should be also taken into account: inter-individual vibration sensitivity and vibration application areas (whole-body or hand transmitted). Vibration sensation is frequency and body-temperature dependent [5-7, 9]. Moreover, individual properties (body mass index, weight, posture) influence the perception of the input signals. The area of stimulation may play an important role. Some authors have shown that the lower area of the human back as well as the hand and the arms of the subjects are more sensitive than the upper and the middle back to vibratory inputs [3, 4, 11]. Thus, a different construction of the test system, such as attachment of mini-bass shakers under the arms or various stimulation zones with different frequencies [3]; alternative signal processing algorithms in accordance with the processing strategy of the CI model and the subject's hearing capacity, as well as embodiment of individual characteristics in the resulting data [5], could indicate greater enhancement. Furthermore, the experience with the CI device and vibrotactile stimulation could contribute to interindividual differences across the subjects which may be eliminated by training courses and musical exposure.

However, taken together, the beneficial effects of vibrotactile stimulation presented in this study and the suggested improvements, indicate that this listening technology for CI-users should be further examined.

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