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Preservation of Rhythmic Clocking in Cochlear Implant Users: A Study of Isochronous Versus Anisochronous Beat Detection

Irene Kim, BSc[1], Eunice Yang, BA[1], Patrick J. Donnelly, MSE[1], and Charles J. Limb, PhD[1]

Abstract

The capacity for internal rhythmic clocking involves a relationship between perceived auditory input and subsequent cognitive processing by which isochronous auditory stimuli induce a temporal beat expectancy in a listener. Although rhythm perception has previously been examined in cochlear implant (CI) users through various tasks based primarily on rhythm pattern identification, such tasks may not have been sufficiently nuanced to detect defects in internal rhythmic clocking, which requires temporal integration on a scale of milliseconds. The present study investigated the preservation of such rhythmic clocking in CI participants through a task requiring detection of isochronicity in the final beat of a four-beat series presented at different tempos. Our results show that CI users performed comparably to normal hearing (NH) participants in all isochronous rhythm detection tasks but that professionally trained musicians (MUS) significantly outperformed both NH and CI participants. These results suggest that CI users have intact rhythm perception even on a temporally demanding task that requires tight preservation of timing differences between a series of auditory events. Also, these results suggest that musical training might improve rhythmic clocking in CI users beyond normal hearing levels, which may be useful in light of the deficits in spectral processing commonly observed in CI users.

Keywords

music, temporal, pattern, pulse

Introduction

Although improvements in cochlear implant (CI) technology have enabled the restoration of open-set speech recognition for many individuals with profound hearing loss, music perception following implantation is typically poor (Gfeller et al., 2000; Limb, 2006; McDermott, 2004). With regard to specific musical elements, CI users demonstrate significant deficits in pitch perception and timbre discrimination, whereas recognition of tempo and basic rhythm patterns on several test paradigms appears to be generally intact (Cooper, Tobey, Loizou, 2008; Gfeller et al., 2000; Gfeller, et al., 2007; Kong, Cruz, Jones, & Zeng, 2004; Limb, 2006). Furthermore, previous studies have shown that CI users rely strongly on rhythm cues for melody identification, which deteriorates when such cues are removed (Drennan, Rubinstein, 2008; Gfeller et al., 2007; Kong et al., 2004). Rhythm perception in CI users, assessed primarily through rhythmic pattern identification tasks, has also been strongly correlated with speech perception measures (Collins, Wakefield, Feinman, 1994; Fu, 2002; Leal et al., 2003).

Although these studies suggest that CI-mediated rhythmic perception is normal, it must be emphasized that they employed relatively simple tasks such as rhythmic pattern identification that may not have been sensitive enough to reveal limitations in rhythmic perception for CI users (Limb, Molloy, Jiradejvong, & Braun, 2010). In this study, we sought to design a task of rhythm perception for CI users that went beyond a possible ceiling effect observed for simple pattern recognition or tempo differentiation. We therefore focused on the concept of internal rhythmic clocking, which deals with the capacity of an external isochronous stimulus (e.g., a metronome) to induce a temporal clock in a listener (Szelag, Kolodziejczyk, Kanabus, Szuchnik, & Senderski, 2004). The concept of internal rhythmicity is referenced in a number of processing models that deal with the interface between perception and action (Grahn, 2009); within these models, rhythmic clocking (also known as beat perception or synchronization) refers to the extrapolative expectancy that is established with as few as three isochronous beats when

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internal rhythmicity is intact (Patel, Iversen, Chen, & Repp, 2005). Rhythmic clocking is an integral concept in both music and spoken language (Gfeller et al., 2007; Patel, 2003), and it may provide a basis for the observed correlations in performance for these disparate tasks.

The present study investigates the capacity for rhythmic clocking in CI users by employing a task that involves temporal precision on a scale of milliseconds, in comparison to rhythm pattern detection, a task that typically requires temporal integration on a scale of seconds. We approached this idea from two contexts: first, that CI-mediated perception of rhythm has been shown to be generally similar to those of normal hearing (NH) individuals, and second, that musical training might have a beneficial effect on rhythmic clocking in NH individuals (and presumably CI users). Although studies of temporal processing and gap detection in CI users have shown preservation of temporal integrity on the order of milliseconds (Campos, Alvarenga Kde, Frederigue et al., 2008; Moore, Glasberg, 1988), to our knowledge no studies have examined this level of temporal precision in the context of musical rhythm perception in CI users. Here we devised a test of anisochronous rhythm perception in which participants were presented with four percussive beats, the first three of which were perfectly isochronous. The fourth beat was presented either isochronously or anisochronously (slightly before or after the isochronous beat; Figure 1). Participants were asked to identify whether the fourth beat occurred early, late, or in perfect timing with respect to the expected rhythmic clock produced by the first three isochronous beats. Stimuli were presented acoustically to each participant, and performance on the task was dependent on accurate induction of an internal rhythmic clock in the listener. To address the effects of musical training on internal rhythmic clocking, a participant group of highly trained conservatory musicians (MUS) was also included in the study, as we hypothesized that individuals with significant musical training would perform superiorly in rhythmic clocking tasks in comparison to nonmusicians. Due to the literature suggesting that basic rhythm pattern perception is intact in CI users, we hypothesized that CI users would perform comparably with NH participants in this task even though this test was designed to be more difficult than in previous studies. Furthermore, we hypothesized that the MUS group would outperform both groups, reflecting training-related variation in rhythmic clock induction by external auditory stimuli.

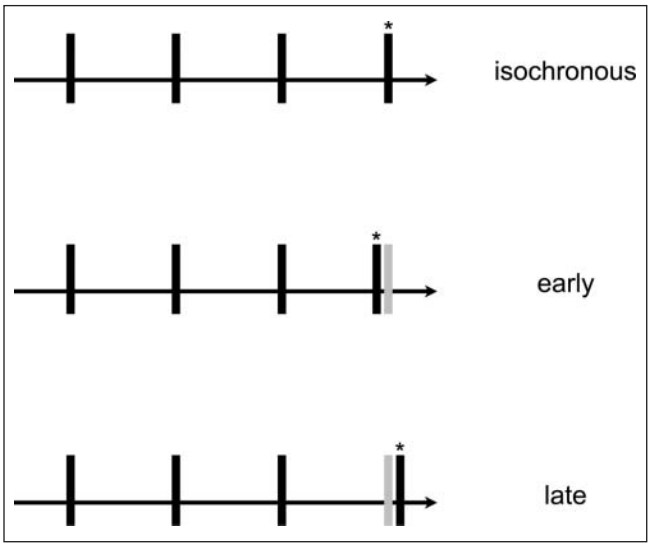


Figure 1. A schematic representation of the anisochronous rhythm perception test stimuli
Note: Each asterisk denotes the fourth percussive beat, which was presented either isochronously (top), slightly early (middle), or slightly late (bottom) in relation to the first three beats. For comparison, the grey bar denotes the isochronous downbeat that would have been predicted from the first three beats.

Method

Study Participants

Thirty-one participants participated in the study. Twelve were normal hearing individuals (4 male, 8 female; age range 21-45, mean 28.4 ± 9.2 years), 12 were cochlear implant participants (5 male, 7 female; age range 27-67, mean 53.1 ± 12.6 years), and 7 were highly trained musicians (nonpercussionists) with normal hearing recruited from the Peabody Conservatory of Music in Baltimore, MD (4 male, 3 female; age range 22-35; mean 29 ± 4.43). All participants were medically screened for any auditory or neurologic disorders. All implant participants were postlingually deafened adults with more than 1 year of implant experience. No CI participants had significant musical experience prior to or after implantation. The devices and processing strategies for each CI user are represented in Table 1. All experiments were performed at the Sound and Music Perception Laboratory at the Johns Hopkins Hospital, and informed consent was obtained for all participants prior to participation according to a protocol approved by the Institutional Review Board of the Johns Hopkins University.

Stimuli

Each category of auditory stimuli consisted of four total percussive beats, presented as either snare drum hits (16 ms peak with 47 ms decay trail) or white noise bursts (63 ms duration) normalized for root mean square power. White noise bursts (flat power spectral density past 20 kHz) were selected due to their broadband nature to minimize differences in CI performance across frequency. Snare drum hits (with peak spectral density below 86 Hz, flat power spectral density to 10 kHz, and linear decay up to 20 kHz) were used as realistic musical sounds that are prototypical of

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Table 1. Cochlear Implant Participant Characteristics

Participant	Sex	Age	CI experience (years)	Device type	Processor
CI 1	M	69	5	ABC HiRes 90K	Harmony
CI 2	F	58	6	CC Nucleus 24	Esprit 3G
CI 3	M	27	2	ABC HiRes 90K	Harmony
CI 4	F	68	1	CC Nucleus Contour	Freedom
CI 5	M	58	5	ABC HiRes 90K	Harmony
CI 6	M	46	2	CC Nucleus Contour	Freedom
CI 7	F	33	4	CC Nucleus 24	Freedom
CI 8	F	54	2	CC Nucleus Contour	Freedom
CI 9	M	47	11	ABC Clarion	Platinum BTE
CI 10	F	56	2	CC Nucleus Contour	Freedom
CI 11	F	67	4	CC Nucleus Contour	Freedom
CI 12	F	54	1	ABC HiRes 90K	Harmony

percussion rhythms encountered in a wide variety of musical contexts. The first three beats were perfectly isochronous, followed by a fourth beat that was either slightly early, isochronous, or slightly late. The four beats were presented at tempos of 60, 120, and 180 beats per minute (bpm), which corresponded musically to slow, medium, and fast tempos. The extent to which the beat was early or late is referred to here as "degree of deviation" from isochrony. For the fourth beat, three such degrees of deviation were tested (1/16, 1/8, or 3/16 fractions of a beat); deviations were introduced before ("early") or after ("late") the isochronous position. For the different tempo conditions, the deviations differed in terms of absolute time but were similar in terms of relative time (see Table 2 for exact timing). Audio source files for the snare drum and noise burst stimuli were recorded using Apple Logic Pro 7.0 platform (Apple, Cupertino, CA). Each participant was presented with a set of 84 stimuli for a total test duration of 20 min. All sets of stimuli, which had an equal number of early, isochronous, and late stimuli as well as an equal number of percussive snare and noise burst stimuli, were presented in randomized order.

Test Procedure

After a brief training session in which the participants were familiarized with the test setup and stimuli, each participant was presented with a set of 84 randomized auditory stimuli. These were presented in a soundproof booth through a single calibrated loudspeaker (Sony SS-MB150H) at a presentation level of 80 dB sound pressure level through an OB822 clinical audiometer (Madsen Electronics). In CI participants, earplugs were used in the nonimplanted ear to diminish the effects of any residual hearing in that ear and also to ensure that participants were listening through the CI alone; all hearing aids were removed and no participants reported being able to hear any stimuli via the nonimplanted ear. Stimuli were presented in a single interval three-alternative forced-choice procedure in which participants were required to indicate whether the fourth beat in the given stimulus was early, isochronous, or late within a 5-s response period (Figure 1). No feedback regarding performance was provided during the formal testing session. The number of correct responses for each participant was averaged and analyzed for all sound sources, degrees of fractional beat deviation, and tempo variations.

Table 2. Millisecond Conversion of Tempo to Beat and Deviation

Tempo (bpm)	Duration of one beat (ms)	Fractional beat deviation	Duration of beat deviation (ms)
60	1000.00	± 1/16	62.50
		±1/8	125.00
		±3/16	187.50
120	500.00	±1/16	31.25
		±1/8	62.50
		±3/16	93.75
180	333.33	±1/16	20.83
		±1/8	41.66
		±3/16	62.50

Results

The results of the rhythmic clocking tasks show that CI users performed comparably to NH participants across all tempos, sound sources, and degrees of deviation (overall mean scores for correct identification of the final beat, CI users: 56.4 ± 13.93% and NH participants: 51.5% ± 13.82%; $p = .143$, unpaired t test). However, the MUS group showed a score of 70.9% ± 5.95% ($p < .0001$ for both MUS vs. CI and MUS vs. NH). A multiway analysis of variance (ANOVA) with participant group, instrument source, tempo, and deviation as factors was also performed, showing statistical significance (unlike the t tests between NH and CI groups) when results from the MUS group were included, $F(2, 28) = 5.32$, $p = .011$.

More specifically, Figure 2 shows insignificant differences in percentage accuracy between CI and NH groups for the two types of rhythmic stimuli (noise and burst) but significant differences in comparison to MUS. When results of the MUS group were included in an ANOVA with participant group and instrument source (noise or snare) as factors, a significant difference was noted; noise, $F(2, 28) = 4.88$, $p = .015$; snare, $F(2, 28) = 5.01$, $p = .014$.

The percentage accuracy between CI, NH, and MUS groups for each tempo is represented in Figure 3. An

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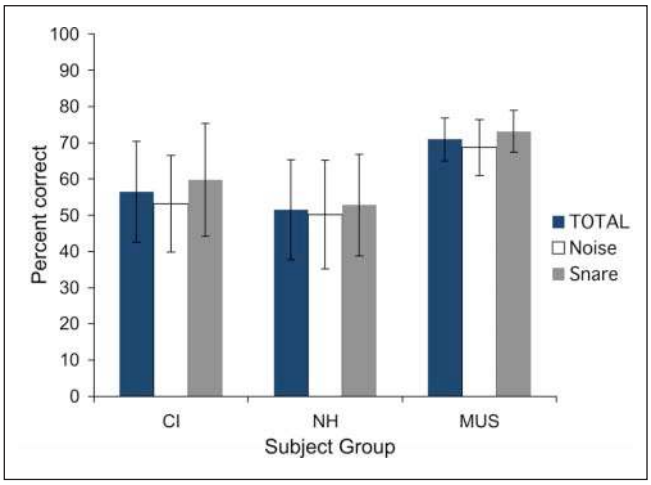


Figure 2. Performance accuracy of each participant group for two types of rhythmic stimuli according to sound sample origin, white noise burst (noise) versus snare drum beats (snare)
Note: Differences between CI and NH groups were insignificant, whereas MUS significantly outperformed CI ad NH participants. Error bars represent standard deviations.

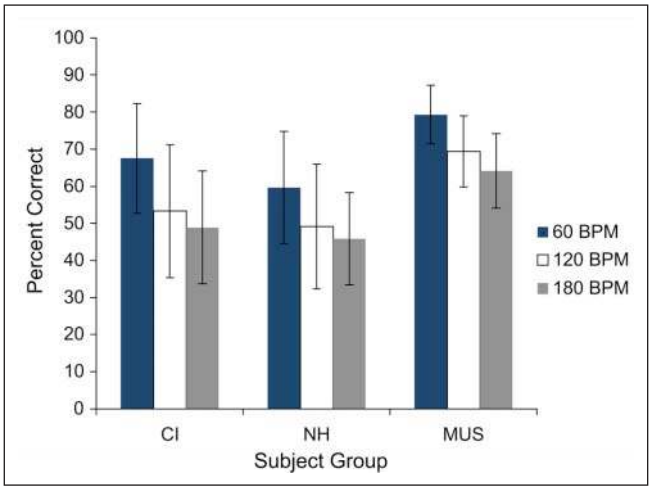


Figure 3. Performance accuracy according to tempo of stimulus presentation
No significant differences were detected among the participant groups regarding the 60, 120, and 180 bpm tempo conditions. Error bars represent standard deviations.

ANOVA of participant group and tempo as factors showed statistically significant differences among the NH, CI, and MUS groups at all tempos; tempo 60 bpm, $F(2, 28) = 4.55$, $p = .019$; tempo 120 bpm, $F(2, 28) = 3.71$, $p = .037$; tempo 180 bpm, $F(2, 28) = 4.60$, $p = .019$. Although faster tempos were harder for all groups, performance differences between groups were preserved at these faster tempos as well.

Figure 4 illustrates the performance accuracy of CI, NH, and MUS groups related to early, isochronous, and late beats. Confusion matrix analysis of the response patterns revealed that CI and NH participants were just as likely to respond "early" or "on time" when presented with the "early" deviation. In contrast, MUS were half were as likely to respond "on time" when presented with the "early deviation" (Table 3).

Table 3. Confusion Matrix Responses of CI, NH, and MUS Participants in Rhythmic Clocking Task

			Reported		
			Early	Normal	Late
CI	Presented	Early	43.39%	53.70%	3.01%
		Normal	0.69%	93.06%	6.25%
		Late	3.01%	40.05%	56.94%
NH		Early	46.76%	49.77%	3.47%
		Normal	7.64%	82.64%	9.72%
		Late	6.04%	47.72%	45.83%
MUS		Early	67.46%	30.56%	1.98%
		Normal	7.15%	90.48%	2.38%
		Late	5.56%	27.38%	67.06%

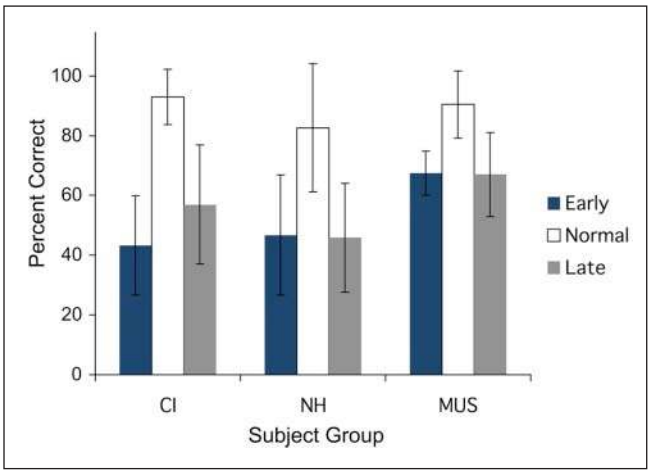


Figure 4. Performance accuracy of CI, NH, and MUS groups to each stimulus category (early, isochronous, late)
Error bars represent standard deviations.

Interestingly, no significant differences between NH and CI participants were noted when early and late stimuli were separated according to degree of deviation, suggesting that CI participants performed as well as NH participants for even the most difficult stimuli (Figure 5). MUS significantly outperformed NH participants in the ±1/8 and ± 3/16 final beat deviations, suggesting that musical experience and training may be related to improved performance in anisochronous rhythm detection tasks (Figure 5). Unpaired *t* tests showed statistical differences in accuracy of final beat identification between NH and MUS groups (–3/16 deviation, $p = .0063$; –1/8 deviation, $p = .017$; +1/8 deviation, $p = .009$; +3/16 deviation, $p = 0.046$).

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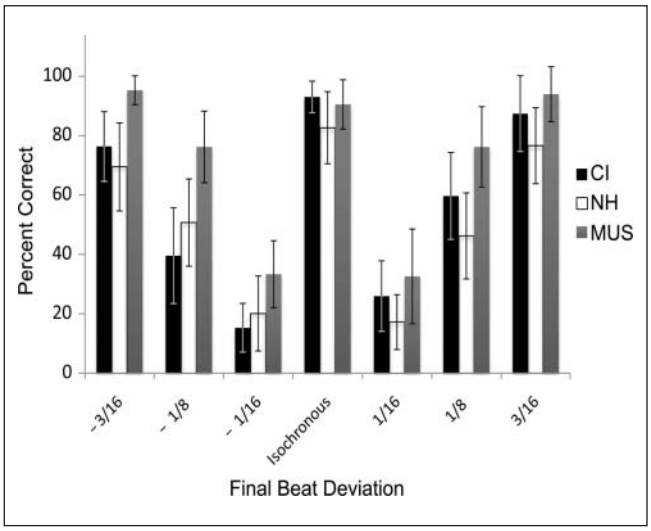


Figure 5. Performance accuracy of all participant groups according to degree of beat deviation
No significant differences were detected in performance between CI and NH participants. MUS demonstrated significantly increased accuracy in detection of both late and early final beat deviations. Error bars represent standard deviations.

Discussion

The present data show that CI and NH participants exhibit similar rhythmic clocking in response to externally presented auditory stimuli. While previous studies (Kong et al., 2004) have shown similar rhythm pattern identification for CI and NH participants, the present study instead required participants to listen to a series of three isochronous beats at a range of tempos and to assess whether a fourth beat was isochronous or anisochronous according to an implicit internal rhythmic clock induced by the first three beats. If anisochronous, participants had to assess whether the beat was "early" or "late" in relation to the anticipated fourth beat. This task differs substantially from identification of beat patterns, a task which can be performed successfully even with impaired rhythmic clocking, due to the fact that small temporal irregularities on the scale of milliseconds do not distort basic rhythmic patterns and that rhythmic patterns are robust to temporal degradation (Huron, 2006). To our knowledge, this report represents the first published data regarding internal rhythmic clocking in CI users. In this study, all stimuli had the same pattern (4 beats presented sequentially either at or close to the downbeat) and differed only by fractions of a second in one beat, as shown in Table 2. We initially sought to perform this study to try to move beyond a possible ceiling effect observed in rhythmic studies for CI users that could be attributable to the use of rhythmic tests that were not sufficiently nuanced enough to detect impaired internal rhythmicity. Because of the small degree of temporal deviation used in these stimuli and the fact that responses were based on only three preceding isochronous beats, we felt that this test would be sensitive enough to allow identification of true performance differences for CI and NH groups. Interestingly, we found that CI participants performed as well as NH controls during this task of anisochronous rhythm detection. There was no statistical difference between performance for the CI and NH groups for any of the stimuli along any parameter. What is perhaps more intriguing is the fact that CI participants actually outperformed NH participants in 5 out of 8 deviation conditions and performed nearly as well as MUS participants in 2 out of 8 deviation conditions (Figure 5). Although not statistically significant, these results may suggest possible adaptations of CI participants to their hearing deficits, such as increased attention to temporal information, an area that deserves further study.

These results lend strong support to the growing body of literature that suggests that rhythm perception is largely intact in CI users. It should be emphasized here that while the present study used a more difficult rhythmic task than other studies (NH participants averaged only 51.49% correct), it is still possible that an even more complex task, such as polyrhythm detection, could indeed reveal subtle differences in rhythmic performance for CI users and NH groups. Also, no studies to our knowledge have examined the temporal accuracy of rhythmic production in CI users beyond basic pattern reproduction (Limb et al., 2010). Last, an age discrepancy existed between our normal hearing and CI groups that reflected the demographics of our cochlear implant patient population and the fact that most of the control participants were students or employees at the university; many of the older control participants that were invited to participate did not have normal hearing and were not tested. As a result, it is difficult to rule out the possibility of an age effect since older participants were part of the CI group (see Gordon-Salant, Fitzgibbons, 1997, 1999 for two studies of age-related effects in CI processing). Despite these caveats, it appears likely that CI participants have reasonably good rhythm perception and that current speech processing strategies commonly employed in modern CI devices are able to transmit temporal patterns with high temporal fidelity.

In light of the above observations, it is notable that MUS outperformed their nonmusician counterparts (both CI and NH) in all elements of the present study. This finding suggests that limitations in performance for difficult tasks may not be based on differences in peripheral auditory stimulation but instead may be attributable to central auditory plasticity in response to focused training. That is, musicians may have performed extremely well on this rhythmic task because of "better brains" (e.g., better signal analysis) rather than "better ears" (e.g., lower auditory thresholds). This finding is consistent with observations for speech perception, in which postimplantation rehabilitation dedicated toward speech comprehension improves performance (Fu, Galvin, 2007, 2008). Musicians were indeed hypothesized to be better at identifying isochronous deviation due to their trained sense of

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internal rhythmicity. It should be noted, that we picked musical ratios (1/16, 1/8, and 3/16 deviations from isochrony) so that we could slave the deviations used to the tempos of the rhythm, rather than using a fixed-interval deviation (e.g. +/– 10, 20, or 30 ms for all tempos) that whose relationship to the downbeat would vary according to the tempo used. As a result, it is plausible that musicians would have an additional advantage on this task since musically relevant deviations from isochrony were employed here. Due to the extreme reliance of CI processing strategies on temporal features of sound, it is critically important that CI users maximize their ability to analyze complex temporal information (McDermott, 2004). Given the present data with trained musicians, rehabilitative training focused on complex rhythmic perception tasks may positively affect CI performance for tasks that require complex temporal processing (Fallon, Irvine, Shepherd, 2008; Looi & She, 2010). Ultimately, CI users may benefit from supranormal performance levels for temporal analysis tasks to offset their deficits in spectral processing.

Declaration of Conflicting Interests

Dr. Charles Limb is a consultant for Advanced Bionics and receives research support for unrelated work.

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References

Campos, P. D., Alvarenga, Kde F., Frederigue, N. B, Nascimento, L. T., Sameshima, K., Costa Filho, O. A., et al. (2008). Temporal organization skills in cochlear implants recipients. *Brazilian Journal of Otorhinolaryngology, 74*, 884-889.

Collins, L. M., Wakefield, G. H., & Feinman, G. R. (1994). Temporal pattern discrimination and speech recognition under electrical stimulation. *Journal of the Acoustical Society of America, 96*, 2731-2737.

Cooper, W. B., Tobey, E., & Loizou, P. C. (2008). Music perception by cochlear implant and normal hearing listeners as measured by the Montreal Battery for Evaluation of Amusia. *Ear Hear, 29*, 618-626.

Drennan, W. R., & Rubinstein, J. T. (2008). Music perception in cochlear implant users and its relationship with psychophysical capabilities. *Journal of Rehabilitation Research and Development, 45*, 779-789.

Fallon, J. B., Irvine, D. R., & Shepherd, R. K. (2008). Cochlear implants and brain plasticity. *Hearing Research, 238*, 110-117.

Fu, Q. J. (2002). Temporal processing and speech recognition in cochlear implant users. *NeuroReport, 13*, 1635-1639.

Fu, Q. J., & Galvin, J. J., III. (2007). Perceptual learning and auditory training in cochlear implant recipients. *Trends in Amplification, 11*, 193-205.

Fu, Q. J., & Galvin, J. J, III. (2008). Maximizing cochlear implant patients' performance with advanced speech training procedures. *Hearing Research, 242*, 198-208.

Gfeller, K., Christ, A., Knutson, J. F., Witt, S., Murray, K. T., & Tyler, R. S. (2000). Musical backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients. *Journal of the American Academy of Audiology, 11*, 390-406.

Gfeller, K., Turner, C., Oleson, J., Zhang, X., Gantz, B., Froman, R., et al. (2007). Accuracy of cochlear implant recipients on pitch perception, melody recognition, and speech reception in noise. *Ear Hear, 28*, 412-423.

Gordon-Salant, S., & Fitzgibbons, P. J. (1997). Selected cognitive factors and speech recognition performance among young and elderly listeners. *Journal of Speech, Language, and Hearing Research, 40*, 423-431.

Gordon-Salant, S., & Fitzgibbons, P. J. (1999). Profile of auditory temporal processing in older listeners. *Journal of Speech, Language, and Hearing Research, 42*, 300-311.

Grahn, J. A. (2009). The role of the basal ganglia in beat perception: Neuroimaging and neuropsychological investigations. *Annals of the New York Academy of Sciences, 1169*, 35-45.

Huron, D. B. (2006). *Sweet anticipation: Music and the psychology of expectation*. Cambridge, MA: MIT Press.

Kong, Y. Y, Cruz, R., Jones, J. A., & Zeng, F. G. (2004). Music perception with temporal cues in acoustic and electric hearing. *Ear Hear, 25*, 173-185.

Leal, M. C., Shin, Y. J., Laborde, M. L., Calmels, M.-N., Verges, S., Lugardons, S., et al. (2003). Music perception in adult cochlear implant recipients. *Acta oto-laryngologica, 123*, 826-835.

Limb, C. J. (2006). Cochlear implant-mediated perception of music. *Current Opinion in Otolaryngology & Head and Neck Surgery, 14*, 337-340.

Limb, C. J., Molloy, A. T., Jiradejvong, P., & Braun, A. R. (2010). Auditory cortical activity during cochlear implant-mediated perception of spoken language, melody, and rhythm. *Journal of the Association for Research in Otolaryngology, 11*, 133-143.

Looi, V., & She, J. (2010). Music perception of cochlear implant users: A questionnaire, and its implications for a music training program. *International Journal of Audiology, 49*, 116-128.

McDermott, H. J. (2004). Music perception with cochlear implants: A review. *Trends in Amplification, 8*(2), 49-82.

Moore, B. C., & Glasberg, B. R. (1988). Gap detection with sinusoids and noise in normal, impaired, and electrically stimulated ears. *Journal of the Acoustical Society of America, 83*, 1093-1101.

Patel, A. D. (2003). Rhythm in language and music: Parallels and differences. *Annals of the New York Academy of Sciences, 999*, 140-143.

Patel, A. D., Iversen, J. R., Chen, Y., & Repp, B. H. (2005). The influence of metricality and modality on synchronization with a beat. *Experimental Brain Research, 163*, 226-238.

Szelag, E., Kolodziejczyk, I., Kanabus, M., Szuchnik, J., & Senderski, A. (2004). Deficits of non-verbal auditory perception in postlingually deaf humans using cochlear implants. *Neuroscience Letters, 355*(1-2), 49-52.

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