Critical Review: The Impact of Structured Auditory Training on Musical Pitch and Melody Perception in Individuals with a Unilateral Cochlear Implant

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This critical review examines whether structured auditory training with unilateral cochlear implant users results in improved performance in the skills of pitch and melody perception. Study designs considered include: a randomized clinical trial (RCT), two single-subject research designs (SSRD), a longitudinal cohort study, and a critical review. Overall, the research provides suggestive evidence in support of structured auditory training to improve pitch and melody perception for the unilateral C.I user. More compelling is a qualitative consideration of the evidence which suggests that auditory training in the form of structured listening experience may contribute to better overall musical enjoyment through a cochlear implant. Thus, the inclusion of structured auditory training within the clinical setting, as part of an aural rehabilitation strategy for the unilateral C.I user, is reasonable according to present research findings.

Introduction

Over the past quarter-century cochlear implants (C.Is) have gained acceptance as a safe and effective form of treatment for sensorineural deafness. Studies have shown that modern C.I systems can provide the successful user with adequate acoustical information to understand speech, using the device alone in most favourable listening conditions (McDermott, 2004). In recent years, more research effort has been directed towards the users' perception of non-speech sounds, especially music (McDermott, 2004). While music may not evidently boast the same adaptive value associated with speech and language, music is an integral aspect of social culture. Music can trigger memories, be a catalyst for significant social and emotional interactions, and has been noted to improve learning effects and quality of life ratings (Gfellar,Witt, Stordahl, Mehr, &Woodworth, 2000). Thus, investigations focused on helping the C.I user regain the experience of musical enjoyment have considerable merit.

A significant finding of past research in music perception with C.Is is that, even with sophisticated technology, the ability to recognize a melody or a change in pitch, especially without rhythmic or verbal cues, is poor with performance at little better than chance levels for most C.I users (McDermott, 2004, Gfeller et al., 2000, Galvin, Fu &Nogaki, 2007). Depleted performance in these skill areas may be due to physiological differences that arise from significant hearing loss, such as increased auditory filter bandwidths, or may be better attributed to limitations in the signal coding and processing strategies employed in current C.I technology that results in limited spectral and temporal resolution (Looi, McDermott, McKay, Hickson, 2008). As pitch and melody perception are particular issues of concern for the C.I user, one area of research has focused on determining if structured auditory training over a period of time may benefit the C.I user in the skills of pitch and melody perception specifically.

Objectives

The primary objective of this paper is to critically evaluate the existing literature regarding the impact of structured auditory training on the skills of pitch and melody perception among unilateral C.I users. The secondary objective is to propose evidence-based practice recommendations based on the reviewed literature related to improving musical experiences for individuals with a unilateral C.I.

Methods

Search Strategy

Computerized databases, including PubMed, Medline, CINAHL, PsychInfo, and Scopus were searched using the following search strategy: (Cochlear Implant) OR (Cochlear Implants) AND (Auditory Training), combined with a separate search for (Cochlear Implant) AND (Pitch Perception) OR (Melody Recognition). The search was limited to human-based research written in English between 1985 and 2009.

Selection Criteria

Studies selected for inclusion in this critical review were required to investigate the impact of a structured auditory training protocol for individuals with a unilateral C.I on the skills of pitch and melody perception specifically. Studies with both post-lingually deafened adults and pre-lingually deafened children were included. This review did not consider individuals with bilateral CIs, nor subjects receiving bimodal stimulation (i.e., both acoustic and electric hearing stimulation) as these treatment scenarios are less common among the current population of C.I users and thus applicable research is limited. No limits were set on outcome measures or the demographics (age, gender, race etc.) of research participants.

Data Collection

Results of the literature search yielded the following articles that were congruent with the aforementioned selection criteria: randomized clinical trial (RCT) (1), single-subject research design (SSRD) (2), longitudinal cohort study (1), and critical review (1). The studies are listed and evaluated from highest to lowest level of evidence.

Results

Impact of Auditory Training using Structured Listening for Pitch and Melody Perception in Adult C.I users.

Randomized Clinical Trial (RCT). Gfellar, Witt, Stordahl, Mehr, and Woodworth (2000) present a study in which the impact of a structured music training protocol was assessed on the C.I users' ability to recognize both simple and complex melodies. A consideration of appraisal (liking) and perceived complexity of the musical stimuli was also considered in this study. Twenty-four post-lingually deafened adults with 12 to 15 months experience with a unilaterally implanted Nucleus C124M C.I were randomized to either a control or training group. Factors such as sex, age, hearing impairment, previous musical background, and previous performance in noise were controlled for. The trained group completed 48 instructional modules (4 modules per week over 12 weeks) via equipment provided by the researchers. A cross-over design was used to control for inherent differences in recognition difficulty between items and to test for generalizability of trained to similar untrained material. To facilitate this study design, two forms of the training (form A and form B) were developed to be identical in basic content and format and groups were randomized to one or the other form. The control group received only incidental exposure to music through normal routine. A detailed description of the specifics of the training protocol and stimuli are provided in the article. Both groups were pre-tested for simple melody recognition, complex song recognition, and song appraisal using tests from the *Iowa Music Perception and Appraisal Battery* developed at the Iowa Cochlear Implant Clinical Research Centre. All subjects were tested again after three months of training.

The results of this study indicated no significant difference in the performance of the trained group with simple melody recognition. Significant improvement from pre-to-post test was found for the recognition and appraisal of complex melodies ($p<0.0001$). Tests of instrument recognition revealed significant improvement in the trained subjects' abilities post-training. In addition, overall quality ratings of the trained subjects increased significantly, while those of the control subjects did not. The authors conclude that structured training can significantly improve some, but not all aspects of music listening for the C.I user and suggest that training depends in part on the structural features of the musical stimuli and whether the implant can transmit an adequate signal of that feature to support learning and perceptual remediation.

Although this study presents an elegant design revealing training effects that are both large and statistically significant, the ability of the subjects to generalize their learned skills for pitch and melody perception was not very clear. For example, the article states that the subjects were only able to recognize a few of the trained simple melody items when tested post-training. However, the same subjects correctly recognized a larger number of unfamiliar complex songs after the training. It is suggested that improved performance may have been due to compensatory strategies rather than a true remediation of pitch perception. It is also suggested that the type of training described may not have been optimal for listening tasks related to pitch and melody recognition. Overall, the relatively sound design, well documented statistical analyses, and thoughtful description of results make this study suggestive of the effectiveness of a training protocol to improve pitch and melody perception abilities of the unilaterally implanted C.I user.

Impact of Auditory Training using Melodic Contour Identification (MCI) on Pitch and Melody Perception in Adult C.I Users

SSRD #1. Galvin, Fu, and Nogaki (2007) investigated whether moderate auditory training with a closed-set melodic contour identification (MCI) task could be used to improve MCI as well as the related skill of familiar melody identification (FMI). The investigators devised a MCI metric task comprising five notes organized in different configurations to generate nine distinct musical patterns and 135 musical contours. FMI was also assessed based on a metric task that involved the recognition of twelve familiar melodies with and without rhythm cues. Baseline MCI and FMI measures were obtained for eleven post-lingually deafened unilaterally implanted adult C.I subjects and nine normal hearing subjects. Initial pre-training results showed MCI to be highly variable among the C.I subjects and uncorrelated with FMI performance. Six out of eleven adult C.I subjects were then trained on the MCI task for at least one hour per day either in sound field or via a laptop computer with custom software. Subjects were allowed to train for as long as they felt it beneficial and thus the time course and amount of training varied among subjects, ranging from one week to two months of training and between one and three hours of training per day. Post-training measures of the metric tests were then obtained periodically for each subject during the training period.

Results indicated that moderate regular training with the MCI task significantly improved all trained subjects' MCI performance (p=0.004). FMI re-testing following the period of training showed that FMI performance, with and without rhythm cues, was also improved with MCI training, however this result was not statistically significant (p=0.373). Training significantly reduced inter-subject variability in MCI performance. Follow-up measures conducted for three subjects one month after training had stopped revealed that performance on the MCI task was largely retained. Overall, the investigators concluded that training with the MCI task helped C.I users, once capable of only limited MCI, to significantly improve their MCI performance, suggesting that C.I users' music perception may be improved with training and music listening experience. Moreover, the MCI training did generalize to improved FMI performance, a skill that was not specifically trained, highlighting the importance of training to develop better music perception skills.

This study is an example of a non-randomized, controlled, concurrent multiple baseline design providing level two evidence for a SSRD (Logan, Hickman, Harris & Heriza, 2007). The authors incorporated various design elements that served to strengthen the quality of their findings within the SSRD framework including: baseline, intervention, and follow-up phases during which repeated outcomes were measured, inclusion of greater than three subjects, and manipulation of exposure. According to Logan et al., (2007) this study provides limited causal inferences for the effect of MCI training on melody and pitch perception. A criticism of this study design is that the authors fail to explain how they selected their six adult C.I subjects for training. In addition, the authors mention that there was high inter and intra-subject variability in the MCI scores pre-training, indicating that stability of the data within the baseline phase before introducing the intervention may not have been adequately established and perhaps posing some threats to internal validity.

SSRD #2. A follow-up study by Galvin, Fu, and Shannon (2009) examined the effect of training using the aforementioned MCI and FMI metric tasks on MCI and FMI performance. This study employed identical methodology to the study previously described. In this study an additional form of MCI training using piano stimuli in the MCI task was provided. After obtaining baseline MCI and FMI measures six post-lingually deafened and unilaterally implanted C.I subjects were trained in the MCI task using the 3-tone complexes. Subjects were allowed to train as long as they felt it was beneficial using custom training software via a laptop for a minimum of a half-hour per day, five days per week, for one month. Four of these six subjects then received the additional MCI training with the piano stimuli. All six subjects returned to re-test baseline MCI and FMI performance periodically during their training period.

The mean improvement in MCI performance across trained subjects was 27 percentage points (range: 14-45.4) with the greatest improvements observed for subjects whose baseline performance was relatively poor. Follow-up measures in three subjects one month or more after training was stopped showed that the improvement in MCI performance was largely retained, although scores were lower than those obtained immediately post-training. Across subjects, mean improvement in FMI performance (without rhythm cues) was 20.8 percentage points, suggesting that MCI training generalized to improved FMI performance. The subjects who received additional MCI training with the piano stimuli did not perform significantly better than subjects trained only using the 3-tone complexes on tests related to pitch and melody perception. However, these four subjects did gain an increased ability to decipher instrument timbre following MCI training with piano-stimuli.

Much like the previously described study, this investigation is level II evidence within the context of SSRDs and thus provides the ability to make limited causal inferences with respect to the effect of the described training on the skills of pitch and melody perception. Both SSRD studies considered here could have been more rigorous had they incorporated a randomized controlled *N-of-1* design. Baseline and intervention phases in both studies were not applied under standardized conditions, meaning that subjects were allowed to train differently and for different periods of time. This particular aspect of the research design may pose some threats to internal validity (Logan et al., 2007). All considered both SSRDs present intriguing findings suggesting that training does have some enhancing affect in pitch and melody perception for the unilateral C.I user.

Impact of Auditory Training using a Take-Home Keyboard Task on Pitch and Melody Perception in Child C.I Users

Longitudinal Cohort Study. Yucel, Sennaroglu, and Belgin (2009) investigated whether children with a unilateral C.I would benefit from training in pitch and music perception. 18 profoundly hearing impaired children with unilateral cochlear implantation aged 8 months to 8 years were included in the study. Nine of the children were trained from the outset while nine children received no training. Both the training and control group employed the same HiRes C.I strategy and were matched for many characteristics, including type and degree of hearing loss, by way of a highly comprehensive audiological evaluation. The training protocol involved a take-home electronic keyboard that was used to administer tasks designed by the investigators targeted toward pitch, melody, and rhythm discrimination. Parents were instructed to train their children for at least 10 minutes per day over a two-year period, however the time course of training was not explicitly controlled as an experimental parameter. Each child trained for approximately two hours per week on average. Parents were requested to document their training sessions with their children in a diary. Both groups of children were assessed for changes in pitch and melody recognition performance using a "*musical stages*" questionnaire administered to the parents and meant to address "*musical attitude*". The questionnaire was administered at 12 and 24 months as part of a post-training test battery that also considered pre and post training performance on various tests of speech recognition and rhythmic perception.

Findings indicated that children in the training group showed significant improvement in determining pitch differences, recognizing melodies, and identifying the correct words to songs ($p<0.05$) compared to the control group. The authors state that by the end of the second year the trained group developed more than the control group on all aspects of musical skills. An interesting observation was that trained children also performed better in areas of word recognition, verbal memory, sensitivity to prosody, and emotional response to music indicating that the learning that might have occurred with training in musical parameters like pitch and melody, might have transferred to other auditory contexts and to other skill areas that were not explicitly trained.

This study provides level II evidence and suggests that the auditory training produced significant improvement in the areas of pitch and melody perception for the trained C.I subjects. The children in the control group were recruited from another study that examined the "changes of sound quality perception". It is not clear what kind of acoustic exposure the control subjects may have received as part of this other study, however the fact that the control group performed more poorly than the trained group provides even stronger evidence in favour of the training. While the authors made noteworthy attempts at controlling many important subject variables such as age, hearing loss, and C.I processing strategy between groups, they did not randomize their subjects nor did they control the duration or type of training received by the study subjects. The investigators provide a table that reveals that some children were trained much more frequently and for much longer than other children. While this lack of control over the training may pose some threats to internal validity the practicality of the training method employed contributes largely to the external validity of this study. Finally, while the questionnaire method of evaluation is realistic given the population in question, the study design would have been more rigorous had it incorporated some sort of quantitative measure for comparing performance in pitch and melody discrimination pre and post training. Current research has indicated that cortical development following auditory stimulation after a period of deprivation can be tracked by measuring the latency periods of cortical auditory evoked potentials during childhood (Dorman et al., 2007). This type of data would add an additional layer of evidence to a study of this kind.

Discussion

While the C.I provides many hearing impaired individuals with good speech understanding under ideal listening conditions, music perception and appreciation with a C.I continues to present major challenges for most C.I users (Galvin et al., 2007). Music appreciation is the second most commonly expressed desire, after speech perception, among implant recipients, and unlike speech perception, greater perceptual accuracy and enjoyment of music has not been shown to be correlated with length of implant use (Gfellar et al., 2000). Recent research effort has gone into examining whether structured auditory training may provide C.I users with improved musical enjoyment. Certain training studies have focused specifically on pitch perception and melody recognition, being the most challenging skill areas for the C.I user. This critical review has attempted to evaluate the current literature on this topic. Taken together the studies described in this review provide suggestive evidence for the ability of structured auditory training to improve pitch and melody perception skills in individuals with a unilateral C.I. A variety of study designs were considered. All had relatively sound methodology and provided high levels of evidence. In addition, all of the studies provided adequate statistical power and showed a significant effect of auditory training across study design and study population. In order to address some of the mentioned concerns with experimental design and procedure additional research will be required to confirm the reliability and validity of the current findings. McDermott (2004) provides a comprehensive review of music perception with cochlear implants in which he states that auditory training programs devised to provide implant users with structured musical listening experiences may improve the subjective acceptability of music heard through a C.I. From a more qualitative perspective, anecdotal reports of C.I users have provided encouraging reports of how listening experience, sometimes over years, results in improved listening comfort and acceptability of music (McDermott, 2004). A recent anecdote recited by a C.I user to a class of Audiology students revealed that pitch and melody perception did greatly improve for this particular C.I user over time, with concentrated listening practice. This anecdote perhaps eludes to the brain's remarkable ability to reorganize with experience, a phenomenon that has been described in studies related to auditory plasticity and training (Dorman, Sharma, Gilley, Martin, Roland, 2007). Overall, the evidence while suggestive from a research standpoint is compelling from a clinical standpoint. As long as there is no risk of harm to the C.I user, the provision of structured auditory training targeted towards improving aspects of musical perception may provide many potential benefits, not only in music perception but other auditory skill areas, and should be carefully considered by the rehabilitative Audiologist as a treatment option within the clinical setting. Whether or not prolonged periods of training or listening may cause harm to the C.I user is another issue that requires investigation.

Conclusion & Clinical Implications

Based on the existing literature, there is evidence in support of prescribing auditory training for improving pitch and melody perception in the unilateral C.I user. Auditory training in certain skills related to music perception may also lead to benefits such as improved liking and subjective appraisal of sound quality through the prosthesis. Thus, barring risk of harm, the rehabilitative Audiologist may assist implant recipients interested in greater musical enjoyment by suggesting listening experiences that target certain skill areas related to music and by providing realistic expectations for music listening.

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