Critical Review:
Does bimodal stimulation help improve music perception in adult cochlear implant users?

Culford, Curt
M.Cl.Sc (AUD) Candidate
University of Western Ontario: School of Communication Sciences and Disorders

Perceiving the intricacies of music is a task that many cochlear implant recipients have difficulty with despite advances in cochlear implant technology. Certain elements of music cannot be conveyed effectively by electrical stimulation. The perception of pitch is particularly affected and it is hypothesized that the addition of an acoustical hearing aid would provide the cochlear implant user with an increased ability to access pitch information. This critical review examines four studies which investigate the effect of a combined acoustic and electric (bimodal) stimulation pattern on music perception tasks. Results indicate that bimodal stimulation does improve music perception overall. Further explanations are explored and clinical implications and recommendations are included.

Introduction

The underlying purpose and function of a cochlear implant (CI) is to directly stimulate the auditory nerve, thus bypassing the damaged or missing inner hair cells in the cochlea. With severe or profound hearing losses, usually few functioning inner hair cells are present in the cochlea and very little, if any, speech perception benefit can be obtained using acoustic methods of stimulation, such as hearing aids (HAs) (Turner, Reiss, & Gantz, 2008). There are a large number of CI users worldwide and their listening environments can be varied and complex. One such realm of acoustic stimulation that users of cochlear implants are familiar with is music. Listening to music with a CI may not be the same perceptual experience as listening with acoustic amplification or as normal hearing processes but attempts are being made at researching, assessing, and enhancing music perception experienced with cochlear implants.

Music perception is difficult to define as there are several ways of categorizing different sounds as music and cultural- and genre-specific variables also come into play. Despite the difficulty in defining music, research in the area of music perception of individuals with hearing loss has used a common definition. Research studies have followed the assumption that music can be characterized as an organized sequence of sounds that have a small number of fundamental features, including rhythm, melody, and timbre. Additional attributes of sounds, such as harmony and the overall loudness, also contribute to the structure of music. Each of these properties can be described, at least approximately, in terms of physical parameters of acoustic signals (McDermott, 2004). For example, temporal patterns in musical sounds, such as moderately fast variations in loudness, are referred to as rhythm, and occur in the very low frequency range of 0.2 to 20 Hz.

The cochlear implant was designed to enable good speech perception when speech is presented in quiet. While successful in this condition, its performance in delivering music and speech in background noise has been less than ideal (Drennan & Rubinstein, 2008).

The poor speech perception in noise and poor music appreciation in cochlear implant listeners are mainly due to their inability to encode pitch. The poor pitch perception performance of these individuals is believed to be a result of limited spectral resolution, especially the inaccurate encoding of low-frequency information. Low-frequency information is important for both musical and voice pitch perception (Kong, Stickney, & Zeng, 2004). Conversely, many studies have reported that performance on rhythmic pattern perception tasks was similar for implant users and normally hearing listeners (McDermott, 2004).

Cochlear implants can employ a variety of processing strategies that can differ based on manufacturer's algorithm, patient preference, and age of the device. Some processing strategies, such as the HiResolution strategy, attempt to provide greater spectral detail through a high rate of stimulation. The high rate of stimulation is thought to provide finer temporal coding of the acoustic signal to the patient.

A relatively new approach to cochlear implant fitting is the use of a short internal electrode array. The short electrode stimulates the basal end of the cochlea while the low-frequency information is perceived through the patient's residual hearing. The patient would therefore have to have some degree of hearing sensitivity in the lower frequencies and very little or no hearing sensitivity in the high frequencies. Acoustic stimulation provided by a conventional hearing aid can help the user detect low frequency sounds and the CI can obtain information regarding high frequency sounds via electric stimulation. It is thought that the addition of low-frequency hearing would aid in pitch perception by providing access to finer spectral information, which would in effect enhance perception and enjoyment of music. Benefits could also be obtained with an increase in speech recognition in a noisy environment (McDermott, 2004; Gfeller et al., 2007).

Typically, “traditional” CIs use electrode arrays of 22 mm in length, which would place them into the low frequency range of the cochlea, approaching the apex. These are now referred to as long electrode (LE) arrays. Short electrode arrays are typically 10 mm in length and do not encroach into the lower frequency region of the cochlea like the LE array does. The effects of these arrays are further explored in one of the studies examined in this review.

As an increasing number of patients with aidable residual hearing undergo cochlear implantation, interest has grown in examining the advantages of bimodal stimulation (Fitzpatrick, Seguin, Schramm, Chenier, & Armstrong, 2009). The enjoyment of music can have positive effects on patient’s lives and it is important to value the benefits music can bring to an individual.

Objectives

The primary purpose of this review is to critically evaluate the existing literature regarding the effectiveness of bimodal stimulation in improving music perception in adult cochlear implant users.

Methods

Search Strategy

Computerized databases including MEDLINE, SCOPUS, CINAHL, and PubMed were searched using the following search strategy: [(cochlear implant*) AND (amplification) OR (hearing aid*) OR (bimodal) OR (acoustic) AND (music)].

The search was limited to articles written in English. No other limits were used. Additional articles were obtained by examining the reference lists of relevant journal articles.

Selection Criteria

Studies selected for inclusion in this critical review were required to investigate the effects of bimodal stimulation on performance on music perception tasks. The reviewed studies also examine the effects of bimodal stimulation in regards to speech recognition performance and other factors; however this review specifically addresses the effects of bimodal stimulation on music perception. Participants in the studies were required to be adults with sensorineural hearing impairment. There were no restrictions on demographics of the subjects or outcome measures.

Data Collection

A review of the literature yielded four peer-reviewed journal articles. Three of four studies consisted of a single group study design and the fourth study was a between groups design. All studies provided a grade III level of evidence (Dollaghan, 2007).

Results

A recent study by Gfeller, Turner, Oleson, Zhang, Gantz, Froman, and Olszewski (2007) investigated cochlear implant recipients’ performance on pitch ranking and how this relates to melody recognition and speech reception in background noise. They compared pitch perception of CI recipients using bimodal stimulation with those using long electrodes (LE) with several types of processing strategies. Participants included 114 adult CI recipients and a group of 21 normal hearing adults. One hundred one participants belonged to a long electrode group and 13 belonged to a short electrode group which used bimodal stimulation (acoustic plus electric, A+E). As discussed previously, LE cochlear implants are more invasive and have the potential to destroy any residual low frequency hearing that was present pre-implant. It was hypothesized that the LE cochlear implant users would not perform as well as short electrode recipients.

The primary dependent variable in this study was pitch ranking, which is how accurately the participant could determine the direction of pitch change (i.e. higher or lower). Pitch ranking was calculated by dividing the number of correct responses by the total number of trials (six) at each combination of base frequency by interval size. The measure was modeled as a function of the size of the interval, which is the difference in frequency between two sequential pitches, and the base frequency class of the two sequential pitches. Stimuli consisted of pure tones ranging from 131 Hz to 1048 Hz and were presented in pairs of pitches ranging in interval sizes of 1, 2, 3, or 4 semitones. A semitone corresponds to a frequency increment of slightly less than 6% which is the smallest interval on the acoustic piano. The pitch ranking scores for mean accuracy were also correlated with two music perception tasks: a pure-tone frequency discrimination task and a familiar melody recognition task.

Due to the unequal and small sample sizes and a binomial rather than continuous response variable, a generalized linear mixed model was used to analyze the data. In regards to the overall probability of correct responses the normal hearing group was significantly different from the LE group and the A+E group, as would be predicted. For the interaction of pitch ranking and the base frequency of the first pitch in each item, the A+E group showed a deterioration of scores in the higher frequency range, but were greater than the LE group. Frequencies above 500 Hz marked the decline of scores. When interval size was examined, all groups showed greater accuracy as the interval size became larger; however, the NH and A+E group were both more accurate than the LE group as a function of interval size. The NH and A+E groups were more accurate on pitch direction for smaller intervals than the LE group but again, the A+E group showed a decline at higher frequencies. The LE group tended to perform with greater accuracy within the higher frequency range.

The study failed to expand upon the unusual finding regarding the steep decline in performance in ranking pitch for the A+E group. It was not expected that around 500 Hz scores would decline so perhaps it was a result of a physical variable of electrode placement or functioning; the electrode may have influenced response as the frequency increased making the acoustic processing less effective. Even with the interesting trend present, the study yielded strong support that bimodal stimulation can improve pitch ranking. This has implications to music perception as pitch is a fundamental aspect of music. When low-frequency acoustic hearing is present, performance is better than with electric-only stimulation.

Kong, Stickney and Zeng (2005) performed a study with five cochlear implant users who participated in a melody recognition experiment. Stimuli consisted of three sets of 12 familiar melodies, played by single notes. Each melody had rhythmic information removed; therefore, pitch was the only available cure for melody recognition. Each melody consisted of 12-14 notes of its initial phrase. Three sets of twelve melodies were generated in low-, mid-, and high-frequency ranges. Participants were tested in three listening conditions consisting of HA alone, CI alone, and a combined (CIHA) condition. These three conditions were combined with the three melody conditions for a total of 9 conditions. The titles of the 12 melodies were displayed on a computer screen and the participant was asked to choose the melody that was presented. The three melody and three listening conditions were presented in random order.

Melody recognition performance varied remarkably from participant to participant in all listening conditions; performance ranged from an average of 19% correct for one participant to 90% for another in the HA alone condition. Similar discrepancies were found for the CI alone condition (8 to 81%) and bimodal condition (21 to 92%). A difference in processing strategies was observed with one strategy (SAS) producing better melody recognition than another (CIS) strategy; however, with the small sample size the effect may not be applicable to generalize.

The average melody recognition performance across all participants and conditions was 45% when participants used the HA alone. The HA alone produced on average 17 percentage points better melody recognition than the averaged CI alone performance, but showed similar performance to the bimodal hearing condition. This was true for four out of the five participants; the remaining participant discontinued regular use of his hearing aid so was not counted.

In regards to melody recognition, results are consistent with increased performance from bimodal stimulation, with the low-frequency acoustic hearing producing significantly better performance than the electric hearing.

Sucher & McDermott (2009) conducted a study with nine post-lingually deaf adults with 7 months of CI experience. All participants had the same model of cochlear implant (Nucleus CI24) and were consistent HA users in the contralateral ear. Music perception and appraisal were examined in three assessments: familiar melody identification (FMI), complex sound identification (CSI), and sound quality rating (SQR). The FMI task consisted of 7 familiar melodies and participants were asked to identify each melody from a randomized closed set of seven melodies. The CSI task consisted of sounds grouped into four categories: single instrument, musical group, environmental sounds, and speech. The sounds were presented four times in random order and the participants had to identify the sound as it was presented. For final part of the experiment, participants were asked to rate the aforementioned set of environmental and musical sounds using a 10-point scale, '1' indicating the sound as completely unrecognizable and '10' corresponding to the stimulus as being exactly as it was experienced before deafness. Tests were performed in three conditions: CI alone, HA alone, and bimodal stimulation (CIHA).

One-way repeated measures ANOVAs were conducted to compare CI, CIHA, and HA results for each assessment. The FMI scores were significantly higher in the CIHA and HA conditions ($p < 0.05$) than in the CI condition; however, there was not a significant difference between the bimodal and hearing aid only scores. Mean CSI scores were significantly higher in the CIHA condition than in the CI and HA conditions ($p < 0.05$) and the CI and HA scores did not differ significantly. The mean SQR ratings were significantly higher for the CIHA condition than the HA condition ($p < 0.05$). There was no significant difference in ratings found between the CIHA and CI conditions or the CI and HA conditions.

The study did not explicitly provide numerical data apart from a single graph where the three tasks were plotted against percentage correct for each listening condition. Additionally, not all participants completed each task and there was no explanation why this was the case. Five of nine completed the FMI task, all nine completed the CSI task, and seven of nine completed the SQR task. Having more participants can increase the power of finding an experimental effect and more accurate comparisons between tasks could be performed.

There was no information provided on the participant's hearing loss or type of amplification. If there are large differences between participants' hearing thresholds this could influence task performance. The amount of residual hearing would also impact the degree to which the stimuli could be heard and could also influence task performance.

The Sucher and McDermott study (2009) had a reasonable level of evidence despite its limitations. Results supported the research question that bimodal stimulation provides better performance on music perception tasks. In addition, the subjective measures indicated that participants preferred the bimodal condition when listening to music rather than CI or HA alone.

El Fata, James, Laborde, and Fraysse (2009) conducted a study where the primary aim was to evaluate the performance of bimodally stimulated recipients of standard CI on a popular song recognition task and to evaluate the self-reported subjective benefit of such stimulation. A secondary objective was to relate the amount of residual hearing to the possible benefit of bimodal stimulation.

Fourteen adult CI recipients with contralateral HAs participated in the study. Low frequency residual hearing was present in all subjects, with pure tone air-conduction thresholds for 125 to 1000 Hz ranging from 25 to 97.5 dB. Musical stimuli with lyrics consisted of single excerpts taken from original recordings of popular songs by the original singer/artist. The same excerpts were also prepared without lyrics where the sung melody was played on a musical instrument with similar backing music. Participants were asked to indentify the excerpt from a list of 15 popular songs which were familiar to them. Listening conditions were fixed in order: bimodal stimulation first, CI alone, and then HA alone; the set of 15 excerpts were presented in each condition first with lyrics and then without lyrics. At the end of testing participants were asked which condition yielded the best subjective perception of music compared to the period before deafness.

For excerpts with lyrics the mean recognition score for the bimodal condition (76.5%) was nearly identical to the score obtained using CI alone (75%). These scores were higher than for HA alone (54.5%). When lyrical content was removed, recognition scores dropped in all listening conditions. For CI alone this drop was most pronounced shifting from 75% to 34.3% and the smallest difference occurred for HA alone (54.5 vs. 43%). To investigate the possible role of residual hearing levels on song recognition scores, residual hearing was categorized for each participant by median thresholds of 125, 250, 500 and 1000 Hz. Next the authors divided the participants into 2 groups based on their median thresholds. Eight participants were included in a 'group I' with median thresholds less than 85 dB HL and the remaining 6 participants with median thresholds ≥ 85 dB HL were placed in a 'group II'. Mean song recognition scores were greater for group I than for group II, for both with and without lyrics (81.5 vs. 69.8% with lyrics; 57.2 vs. 26.3% without lyrics), for the bimodal condition and for the HA alone condition. However, mean scores for CI alone did not differ significantly between the 2 groups (71.5 vs. 79.8% with lyrics; 38.8 vs. 28.3%).

An ANOVA was performed on scores for all participants and for groups I and II separately. Group I showed significant differences in scores for bimodal versus CI alone, both with and without lyrics, and for HA alone versus CI alone without lyrics. The only significant differences for group II were found when songs were presented with lyrics, where scores for bimodal and CI alone were significantly better than for HA alone.

The majority of participants (10 of 14) considered bimodal stimulation the most enjoyable way to listen to music and all except 2 of these belonged to group I. The 4 participants who preferred using CI alone belonged to group II. As well the majority of the participants (42.8%) considered the music to have a similar contour compared to their recollection pre-deafness and most of those participants belonged to group I. For those participants that stated that the music had an altered contour (35.7%) most belonged to group II. While it can be beneficial to ask participants the method they prefer to listen to music, such a subjective approach to comparing perception of music now to that which they experienced pre-deafness may not be an accurate reflection. The mean duration of deafness prior to implantation was 8.6 years so answering based on memory may be flawed. Perhaps if there were some objective scores to compare pre- and post-deafness more could be taken from the above statement.

El Fata et al. (2009)'s study supplemented the pool of evidence finding that bimodal stimulation provides better perception of popular music, particularly melody recognition, when compared to CI alone. One caveat is that this was true for individuals with residual low-frequency hearing being better than 85 dB HL. When hearing level thresholds were greater than this they found that bimodal stimulation was not significantly different than CI alone.

Discussion

A limitation that is consistently encountered across the examined articles is the lack of information regarding the fitting and verification of the participants' hearing aids. There was no mention of how, or even if, the participants' hearing aids were verified before testing commenced. If the hearing aids were not properly fitted to the participant's hearing loss, this could affect recognition scores as they may not perceive the stimulus in an effective matter. The HA alone condition may be affected but more importantly for this review, the bimodal condition could be negatively impacted; an improperly fit hearing aid could be detrimental to the perception of pitch and in turn affect music perception. A surprising observation was the Gfeller et al. (2007) did not have a HA alone condition to test for residual hearing. The other studies in this critical review had a HA alone condition. The lack of this condition is one example of the heterogeneity of testing procedures in this realm of research.

A question may arise regarding length of implant use on performance on such perception tasks. Gfeller et al. (2007) found that duration of implant use was negatively correlated with pitch ranking, indicating that increased length of cochlear implant use does not result in improved pitch ranking. These correlations are consistent with prior studies that show little improvement as a result of everyday cochlear implant use for music perception tasks related to pitch.

Some researchers have questioned that a 'mix' of electrical and acoustic stimulation could be detrimental or interfering. Results from El Fata et al. (2009) show that participants (those from group I) found music more enjoyable and more natural sounding when they combined modalities. A summation effect was found as well for bimodal stimulation, increasing recognition scores 10 percentage points. For participants with median thresholds >85 dB HL there was no significant difference for bimodal stimulation versus CI alone. Scores for this group of participants was very poor (20-30%) when stimuli were presented without lyrics. El Fata et al. (2009) propose that a limit of about 80 dB HL would be useful for counseling patients on the likely benefit of bimodal stimulation for listening to music.

Another point that came up in the literature was the role of the contralateral ear itself. Some research suggest that if, as is often the case, the ear contralateral to the implant is the ''better'' ear, then improved speech recognition performance in the binaural condition may have little to do with combined acoustic plus electric hearing, and instead be primarily a reflection of the better ear's status. Even when this factor is taken into account, the evidence is clear that combining acoustic and electric hearing across ears can provide a substantial advantage for many patients (Turner, Reiss, & Gantz, 2008). This information combined with the data gathered in the four articles examined in the present evaluation, suggest that for most bimodal users, the electric and acoustic signals will not degrade perception of music.

As mentioned previously, music perception can be rather elusive to define and is composed of several acoustical elements. Not all of the studies reviewed examined the same elements of music perception. Caution would need to be exercised if one were to make statements regarding the effect of bimodal stimulation on specific elements of music perception. Current studies focus mainly on pitch and melody so to say that bimodal stimulation unequivocally enhances music perception may not be an entirely accurate statement. It would be more accurate to state that bimodal stimulation would likely improve pitch perception and melody recognition. Future research should include several musical elements or variables and see how performance relates across them.

The relatively small amount of current research specifically on bimodal stimulation and music perception suggest that this topic is new but research on cochlear implant processing and music perception has been around for quite some time. The investigation into bimodal stimulation has been gaining promise and will no doubt be continued into the near future.

Conclusion & Clinical Implications

Based on the research examined bimodal stimulation has the potential to enhance the cochlear implant recipient's enjoyment of music. This is especially true when the user has residual low frequency hearing (either in the implanted or non-implanted ear) and when their thresholds are less than 85 dB HL. Recommending a hearing aid will also depend on client factors such as cost, aesthetics, patient's experience with hearing aids and clinical resources (Fitzpatrick et al., 2009) but counseling the patient on the option of bimodal stimulation may provide them with the opportunity to enjoy music and other pitch-related activities in the future.

References

Dollaghan, C. (2004). Evidence-based practice in communication disorders: What do we know, and when do we know it? *Journal of Communication Disorders, 37*, 391-400.

El Fata, F., James, C. J., Laborde, M.-L., & Fraysse, B. (2009). How much residual hearing is 'useful' for music perception with cochlear implants? *Audiology and Neurotology, 14*(Suppl. 1), 14-21.

Fitzpatrick, E. M., Seguin, C., Schramm, D., Chenier, J., & Armstrong, S. (2009). Users' experience of a cochlear implant combined with a hearing aid. *International Journal of Audiology, 48*, 172-182.

Gfeller, K., Turner, C., Oleson, J., Zhang, X., Gantz, B., Froman, R., & Olszewski, C. (2007). Accuracy of cochlear implant recipients on pitch perception, melody recognition, and speech reception in noise. *Ear and Hearing, 28*(3), 412-423.

Kong, Y., Stickney, G. S., & Zeng, F. (2005). Speech and melody recognition in binaurally combined acoustic and electric hearing. *Journal of the Acoustical Society of America, 117*(3), 1351-1361.

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

Sucher, C. M., & McDermott, H. J. (2009). Bimodal stimulation: Benefits for music perception and sound quality. *Cochlear Implants International, 10*(S1), 96-99.

Turner, C. W., Reiss, L. A., & Gantz, B. J. (2008). Combined acoustic and electric hearing: Preserving residual acoustic hearing. *Hearing Research, 242*, 164-171.