Music Appreciation after Cochlear Implantation in Adult Patients: A Systematic Review

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Abstract

Objective. The cochlear implant (CI) improves quality of life for people who are severely and profoundly deafened, allowing implantees to perceive speech at levels similar to those of individuals with normal hearing. However, patients with CIs generally report a reduced appreciation of music after implantation. We aimed to systematically review the English-language literature for studies evaluating music enjoyment and perception among adult patients with CIs.

Data Sources. A systematic review of PubMed/MEDLINE, Scopus, Embase, and the Cochrane Library.

Review Methods. The PRISMA statement was utilized to identify English-language studies reporting music appreciation among adults with CIs. Two independent reviewers performed searches through May 2017. Included studies investigated parameters related to music enjoyment and music perception, including (1) pitch and timbre perception, (2) noise-canceling algorithms, and (3) the presence of dissonant chords, lyrics, or visual cues.

Results. A total of 508 articles were screened for relevance. Forty-one full-text articles were evaluated, and 18 met final inclusion criteria. Studies used heterogeneous methods of outcome measurement for identifying music appreciation. The outcome measures suggest that rhythm and lyrics are important components of enjoyment. Patients with CIs had difficulty with pitch and timbre perception.

Conclusion. The heterogeneous outcome measures identified in this systematic review suggest that rhythm and lyrics are important components of enjoyment, while patients with CIs had difficulty with pitch and timbre perception. Because there is no standardized reporting metric for music appreciation among adult patients with CIs, a standardized validated outcome-measuring tool is warranted.

Keywords

music appreciation, cochlear implantation, postlingual, deaf

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The cochlear implant (CI) is a historic medical advancement that has improved quality of life (QOL) for people who are severely and profoundly deafened.¹ Although CI users perceive speech at levels similar to those with normal hearing, music perception and enjoyment often remain limited.² Music affects daily life, culture, and emotion, and music improves QOL following implantation.³

Patients with CIs hear differently than do those with normal hearing. While implants mimic the tonotopic map of the cochlea, they typically have only 12 to 22 electrodes, significantly decreasing the number of perceived frequencies versus the hair cell system.⁴ Consequently, CI users need about 25% difference between fundamental frequencies to detect a change in pitch, a much larger difference than that of individuals with normal hearing.²

CI users report a reduced ability to appreciate music after implantation. A comparison of self-assessments before deafness and after implantation demonstrated reduced music enjoyment.⁵ Many studies sought to show that reduced enjoyment is due to difficulty with music perception. For example, Caldwell et al⁴ found that CI users cannot detect minor changes in frequency, resulting in decreased pitch perception. As a result, they concluded that patients with CI enjoy music less. However, other studies showed that lack of perception does not inhibit enjoyment of music among

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CI users. Enjoyment and subjective appreciation do not always reflect perceptual abilities, because enjoyment is dependent on personal, situational, and emotional variables. Even with decreased perception, CI users continue to listen to music after implantation.

Musical perception is reliant on information transmitted to the auditory system, such as timbre, pitch, and melody. CIs are limited in their ability to transmit this complexity of sound to the auditory system. Pitch perception is the ability to detect notes on a musical scale; timbre refers to the different sound quality of 2 instruments playing the same note; and complexity involves overlaying multiple elements of music at once, such as harmonies, multiple melodies, or multiple instruments. While subjects with normal hearing differentiate instruments on the basis of spectral and temporal cues, spectral content is not feasible for CI users. Instead, patients with CIs rely heavily on temporal cues. Additionally, complex music is difficult because CIs degrade acoustic cues so that the user can differentiate sound sources. CI users therefore cannot hear multiple lines of melody or perceive different instruments and voices adequately.

Prior work demonstrated that patients with CIs prefer music with specific characteristics, such as simple, monophonic melodies and a clear rhythm and beat, as well as music with an emphasis on vocals, drums, and bass, especially in songs with higher complexity. Lyrics can augment enjoyment owing to the additional cues of spoken words. Rock, pop, country, and orchestral music are considered complex and less enjoyable, although lyrics can improve their accessibility. Otherwise, these genres are regarded as unpleasant, noisy, and annoying.

The objective of this study was to systematically review the literature to evaluate music enjoyment and perception among adults with CIs listening to musical excerpts.

Methods

Search Strategy

Authors A.M.T. and P.E.R. independently searched PubMed/MEDLINE, Scopus, Embase, and the Cochrane Library from inception through May 10, 2017. MeSH search terms, keywords, and phrases included “cochlear implant,” “middle ear implant,” “cochlear prosthesis,” “auditory prosthesis,” “music,” “music therapy,” “melody,” and “song.” An example of a PubMed/MEDLINE search strategy is as follows: ((Cochlear Implant OR middle ear implant OR Cochlear Prosthesis OR Auditory Prostheses OR “Cochlear Implants”[Mesh]) AND (music OR music therapy OR melody OR Song[tiab] OR songs OR “Music”[Mesh] OR “Music Therapy”[Mesh])). All potentially relevant studies were cataloged. The full-text versions of the articles were then downloaded and reviewed for determination of inclusion in this review. References of each study were scanned for relevant studies as well. The PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-analyses) was followed throughout this review.

Study Selection

The following inclusion criteria were required (based on the PICOS acronym):

- **Patients:** adults (≥18 years) with CIs
- **Intervention:** observation of CI users while listening to musical excerpts
- **Comparison:** enjoyment and perception as compared with individuals who have normal hearing
- **Outcomes:** interpretation of music appreciation, including (but not limited to) pleasantness, musicality, naturalness, pitch perception, timbre discrimination, and musical memory
- **Study design:** cross-sectional and prospective studies in English

We excluded retrospective studies, review articles, longitudinal studies, and studies exclusively examining questionnaires without presenting musical excerpts. Additionally, we excluded subject populations composed only of subjects who were early deafened/late implanted.

Data Abstractions and Study Quality Assessment

After the systematic search, A.M.T. and P.E.R. came to a consensus about which studies met the inclusion criteria. Full-text articles were digitally stored. Data collected from the studies included patient demographics, pitch perception, and factors affecting music perception and enjoyment. The National Institute for Health and Care Excellence quality assessment tool was used to evaluate the quality of the included studies. The Newcastle-Ottawa Scale, a validated scale for assessing risk of bias in systematic reviews, was used to assess included studies. Risk of bias according to the scale was independently determined by A.M.T. and P.E.R. Discrepancies were discussed and consensus achieved.

Results

The initial query identified 508 articles which were screened for relevance to music appreciation among adults with CIs. Duplicates were removed, and 467 studies were excluded due to irrelevance to music appreciation. Forty-one full-text studies were downloaded for detailed evaluation. Studies that were considered further were observational, prospective, and cross-sectional studies. Studies that were included examined enjoyment of music, music perception, or both. Examination of enjoyment included questioning subjects on pleasantness, musicality, naturalness, preference, interest, understanding, and emotion evoked. Examination of perception included questioning subjects on pitch pattern and recognition, rhythm, timbre discrimination, melodic contour, interval, meter, melodic memory, impact of linguistics, effects of noise-canceling algorithms, visual cues, presence of lyrics, and instrument recognition. The following studies were excluded: 1 review article, 1 study on subjects who were early deafened/late implanted, 4 studies with pediatric participants only, 1 study with the intervention of round window implantation but no musical excerpt experiment,
1 longitudinal study, 1 study composed only of patients with normal hearing, and 14 studies without musical excerpt experiments. No additional studies were added after manually searching reference lists. A total of 18 full-text articles met criteria for inclusion for qualitative analysis (Figure 1).

**Methodological Quality of Included Studies**

The studies included in this review were all prospective (Table 1). All studies satisfied at least 8 of the 11 applicable items on the National Institute for Health and Care Excellence quality assessment tool. Risk of bias, as determined by the Newcastle-Ottawa Scale, revealed a moderate degree of bias risk in the selected studies. There were 619 patients with an age range of 18 to 87 years. Slightly more than half of patients were men (53.2%). Table 2 details characteristics of CI users in the studies, including duration of device use prior to enrollment, device coding strategy, and bilateral versus unilateral implantation.

**Music Perception**

The 18 studies utilized various metrics to examine the difference between CI users’ appreciation and perception of music (Table 3). Parameters included digital normalization, audio track mixing, enhancing vocals and bass, increasing dissonant chords, frequency programming, effects of lyrics, input compression, visual cue effects, noise reduction algorithms, harmonic series reduction, and dichotic listening.

After patients listened to musical excerpts, alterations in appreciation or perception were determined by an array of outcome measures, including the Music EAR test, subjective preference, Likert scales, Munich Music Questionnaire, MACareena software, Complex Melody Recognition Test, and visual analog scales. There was significant heterogeneity in the tools used to measure the outcome of music appreciation.

Pooling data across multiple studies based on the same outcome measure was attempted. Formal meta-analysis was not feasible because of insufficient comparative outcomes. This pervasive heterogeneity precluded meaningful pooling of weighted outcomes.

Seven studies focused on pitch as it relates to music perception. Au et al found that CI users had difficulty perceiving pitch and timbre alterations as compared with individuals with normal hearing. Caldwell et al found that introducing dissonant chords into music did not affect CI users’ rating of pleasantness as compared to those with normal hearing who found these changes less pleasant. Pitch perception tests conducted by Cooper et al revealed that CI users performed at near chance in determining the correct pitch. These tests included a test of contour, interval, and scale, which encompass different aspects of pitch perception. Nemer et al sought to simplify pitch by decreasing harmonics, which led to an increase in enjoyment for CI users. Falcon-Gonzalez et al altered the frequency programming of individuals’ sound processors. This resulted in an improved perception of instrument recognition, tonal scales, and harmonics, specifically with bilateral implantation. Cullington and Zeng studied pitch tests in the context of bimodal hearing. They found that bimodal hearing resulted in better pitch test results than bilateral CI use; however, this was not statistically significant. Additionally, Crew et al examined bimodal hearing in the context of pitch perception—specifically, melodic contour identification. Their study found that bimodal hearing did not improve melodic contour identification. Each of these studies found that pitch continues to be problematic for CI users.

While not specifically evaluating pitch perception, Rahne et al looked at altering the spectral content of music—in this case, the fundamental frequency—with the intent of determining CI users’ ability to discriminate timbre. The just noticeable
<table>
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<td>22:22, NH; 17:27, CI</td>
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<td>23:17</td>
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<td>3:14, NH; 50:37, CI</td>
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Abbreviations: BL, bilateral; BM, bimodal; CI, cochlear implant; F, female; HA, hearing aid; M, male; N, no; NA, not applicable; NH, normal hearing; NICE, National Institute for Health and Care Excellence; Y, yes.

*NICE checklist for quality assessment of cohort and cross-sectional studies: (1) “Was the research question or objective in this paper clearly stated?” (2) “Was the study population clearly specified and defined?” (3) “Was the participation rate of eligible persons at least 50%?” (4) “Were all the subjects selected or recruited from the same or similar populations (including the same time period)?” Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants? (5) “Was a sample size justification, power description, or variance and effect estimates provided?” (6) “For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?” (7) “Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?” (8) “For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?” (9) “Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?” (10) “Was the exposure(s) assessed more than once over time?” (11) “Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?” (12) “Were the outcome assessors blinded to the exposure status of participants?” (13) “Was loss to follow-up after baseline 20% or less?” (14) “Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?”
difference in timbre was different among those with normal hearing, users of bone-anchored hearing aids, and CI users.

**Music Enjoyment**

Eight of the reviewed studies directly examined enjoyment outcomes. Alexander et al.\(^3\) and Au et al.\(^2\) concluded that CI users had enjoyment levels similar to those of people with normal hearing. Input compression and noise-canceling algorithms did not increase enjoyment among CI listeners, as found by Halliwell et al.\(^{21}\) and Kohlberg et al.\(^{15}\) respectively. Vannson et al.\(^{22}\) found that improved clarity through dichotic listening led to increased preference. Nemer et al.\(^{16}\) discovered that by decreasing harmonics (i.e., simplifying pitch), CI users had increased enjoyment of the presented musical pieces. Conversely, Wright and Uchanski\(^{23}\) found that enjoyment may be independent from music perception, such as pitch perception.

**Temporal Music Cues and Vocals**

Six studies examined the effect that temporal aspects of music had on enjoyment and perception. Au et al.\(^2\) Buyens et al.\(^{20}\) and Buyens et al.\(^{10}\) each found that CI users preferred percussive instruments. In contrast, the 2015 study by Kohlberg et al.\(^{14}\) found that including rhythmic instruments did not increase enjoyment among CI users. Vannson et al.\(^{22}\) found that preference for music and clarity improved with a fast tempo, whereas Cooper et al.\(^{17}\) found that CI users had better perception of temporal cues. CI users had a greater understanding of rhythm and meter during these specific experiments.

The importance of vocals was studied by 4 articles. Gfeller et al.\(^{13}\) found that introducing linguistic cues improved perception. The 2014 Buyens et al.\(^{10}\) study found that CI users preferred music to have an increased vocals:instruments ratio, and the 2015 article by Buyens et al.\(^{9}\) also indicated that CI users prefer an emphasis of vocals. The 2015 Kohlberg et al.\(^{14}\) study had similar findings that decreasing vocals did not improve enjoyment for CI users.

Innes-Brown et al.\(^{24}\) were the only authors to investigate the role of visual cues on music perception. Their study found that visual cues added in segregating lines of music improved perception of complex music.

**Discussion**

CI users hear music differently than people with normal hearing. CI electrode arrays are less effective in transmitting the natural and distinct sounds of musical instruments.\(^{13}\) Migirov et al.\(^{7}\) demonstrated that while listening habits and perceived quality degraded after implantation, CI users still listen to music and find enjoyment in the activity. Thus, there is a rising demand to improve QOL by restoring music.
Table 3. Parameters and Outcome Measures of Included Studies.

<table>
<thead>
<tr>
<th>First Author</th>
<th>Altered Characteristic</th>
<th>Setting</th>
<th>Outcome Measures</th>
<th>Outcome Measurement Tools</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexander (2011)</td>
<td>Digital normalization</td>
<td>Unclear</td>
<td>Enjoyment, instrumental timbres, pitch pattern variation, target musical patterns in melody</td>
<td>Music EAR Test</td>
<td>CI users’ enjoyment comparable to NH; CI most enjoy classical music; CI significantly poorer perception vs NH</td>
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<tr>
<td>Au (2012)</td>
<td>Variations, percussion / vibraphone, spoken word, pitch, electronic, percussion</td>
<td>Auditorium, combination of prerecorded and live music</td>
<td>Interest, understanding, musicality, enjoyment, localization, timbre recognition</td>
<td>Questionnaire handed out to concertgoers</td>
<td>CI users and NH enjoyment similar; CI highest preference for percussive pieces; perception problematic for CI</td>
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<tr>
<td>Buyens (2014)</td>
<td>Audio track mixing</td>
<td>Sound-treated room</td>
<td>Mix level settings; preference</td>
<td>Slider levels; report preference with rating score (%)</td>
<td>CI users prefer larger vocals:instrument ratio vs NH and louder bass / drum track vs other instruments</td>
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<tr>
<td>Buyens (2015)</td>
<td>Preprocessing scheme to enhance vocals/drums/bass and attenuate “other instruments”</td>
<td>Sound-treated room at level of 60 dB</td>
<td>Preferred setting for attenuation parameter at varying levels of complexity</td>
<td>Report excerpt preference</td>
<td>Preference for emphasis on vocals, drums, bass</td>
</tr>
<tr>
<td>Caldwell (2016)</td>
<td>Presence of dissonant chords by altering harmonic structures of chords</td>
<td>Soundproof booth at 56-dB sound pressure level</td>
<td>Pleasantness</td>
<td>Likert scale for pleasantness</td>
<td>Consonant vs dissonant chord had no significant impact on pleasantness, indicating impaired pitch perception</td>
</tr>
<tr>
<td>Cooper (2008)</td>
<td>Spectral resolution</td>
<td>Sound field in a double-walled attenuating booth</td>
<td>Melody memory; scale, contour, interval, rhythm, meter perception</td>
<td>Montreal Battery of Evaluation of Amusia</td>
<td>CI performed higher on rhythm and meter tests, near chance on pitch tests, significantly higher than pitch but lower than meter/rhythm on memory tests</td>
</tr>
<tr>
<td>Crew (2015)</td>
<td>Melodic contour</td>
<td>Sound-treated booth, sitting 1 m in front of a single loudspeaker</td>
<td>Melodic contour identification</td>
<td>Report excerpt contour identity by multiple-choice option</td>
<td>CI and HA users performance is not improved for melodic contour identification vs CI only</td>
</tr>
<tr>
<td>Cullington (2011)</td>
<td>Scale, contour, interval</td>
<td>Sound-treated booth, sitting 1 m in front of a single loudspeaker</td>
<td>Pitch perception, rhythm and timing perception, musical memory</td>
<td>Montreal Battery of Evaluation of Amusia</td>
<td>Bimodal CI listeners performed better on pitch-related tests than bilateral CI users, not statistically significant</td>
</tr>
<tr>
<td>Falcon-Gonzalez (2014)</td>
<td>Frequency programming of patient’s sound processor</td>
<td>Unclear</td>
<td>Instrument recognition with frequency vs normal programming; music habits</td>
<td>Munich Music Questionnaire and Minimum Auditory Capability software</td>
<td>Improved recognition with frequency programming</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>First Author</th>
<th>Altered Characteristic</th>
<th>Setting</th>
<th>Outcome Measures</th>
<th>Outcome Measurement Tools</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gfeller (2012)</td>
<td>Presence of lyrics</td>
<td>Sound-treated room initial sound level at 70 dBC, permitted to adjust processor for maximum comfort</td>
<td>Impact of linguistic vs nonlinguistic elements on melody recognition</td>
<td>Complex melody recognition test</td>
<td>Melody recognition improved with linguistic cues</td>
</tr>
<tr>
<td>Halliwell (2015)</td>
<td>Input compression, input frequency response; speech processor channel gains</td>
<td>Sound-treated room</td>
<td>Preference between versions of same musical clip</td>
<td>Preference: forced choice</td>
<td>Input compression did not affect enjoyment</td>
</tr>
<tr>
<td>Innes-Brown (2011)</td>
<td>Visual cue effects on segregating musical streams</td>
<td>Room conditions unclear, presented at 65 dB</td>
<td>Difficulty of perceiving 4-note melody continuously</td>
<td>Variable slider on MIDI controller from 0 to 10</td>
<td>Visual cues improve CI users ability to segregate lines of music</td>
</tr>
<tr>
<td>Kohlberg (2015)</td>
<td>Reducing numbers of instruments, excluding vocals, including rhythmic instruments; overall reducing complexity</td>
<td>Soundproof booth</td>
<td>Pleasantness, musicality, naturalness</td>
<td>Visual analog scale from 0 to 10</td>
<td>Fewer instruments were more enjoyable to CI users and NH with CI simulation; excluding vocals and including rhythmic instruments improved enjoyment for NH but not for CI users</td>
</tr>
<tr>
<td>Kohlberg (2016)</td>
<td>Implement noise reduction algorithm</td>
<td>Soundproof booth</td>
<td>Pleasantness, musicality, naturalness</td>
<td>Visual analog scale from 0 to 10</td>
<td>Noise reduction algorithm does not affect enjoyment for CI users</td>
</tr>
<tr>
<td>Nemer (2017)</td>
<td>Harmonic series reduction</td>
<td>Soundproof booth: audiometric suite</td>
<td>Pleasantness, musicality, naturalness</td>
<td>Visual analog scale from 0 to 10</td>
<td>Harmonic series reduction improves enjoyment in CI users and NH individuals with or without CI simulation</td>
</tr>
<tr>
<td>Rahne (2012)</td>
<td>Fundamental frequency to generate various spectra</td>
<td>Acoustically shielded room, stimuli free</td>
<td>Timbre discrimination</td>
<td>Alternative forced-choice paradigm, calculation of spectral shape of just noticeable difference</td>
<td>Just noticeable difference in timbre perception is different among NH, BAHA users, and CI users</td>
</tr>
<tr>
<td>Vannson (2015)</td>
<td>Introducing dichotic listening of bass and treble clef parts</td>
<td>MOTU IO-24 soundcard and headphones</td>
<td>Emotion that clip evoked, whether participant liked the piece, clarity of clip</td>
<td>Three dichotomously anchored continuous rating scales</td>
<td>Dichotic listening improves music clarity, resulting in improved enjoyment; preference and clarity improved with fast tempi</td>
</tr>
<tr>
<td>Wright (2012)</td>
<td>Presence/absence of lyrics, processing with CI simulation software</td>
<td>Single-walled booth</td>
<td>Pitch perception, rhythm, timbre, noise, genre, melody, scale, contour, interval, meter, memory, pleasantness</td>
<td>AMICI, MBEA, UW-CAMP, 7-point rating scale (Likert)</td>
<td>Music is more enjoyable to CI users than NH with CI simulation; enjoyment independent of perception</td>
</tr>
</tbody>
</table>

Abbreviations: AMICI, Appreciation of Music in Cochlear Implantee; BAHA, bone-anchored hearing aid; CI, cochlear implant; EAS, electrical acoustic stimulation; HA, hearing aid; MBEA, Montreal Battery for Evaluation of Amusia; NH, normal hearing; UW-CAMP, University of Washington Clinical Assessment of Music Perception.
appreciation. The main findings of this review were that CI users do enjoy music. This enjoyment is increased with temporal cues, such as fast tempo and percussive instruments; additionally, spectral content is difficult for CI users to perceive. 

Enjoyment for music can be improved by simplifying this content. Finally, linguistic cues improve perception, and CI users prefer music with vocals.9,10,14

In a review of music perception and CIs, McDermott suggested that accurate pitch and timbre perception is important for music appreciation. With improved perception, music appreciation and enjoyment follow. Several studies in this review examined whether adding features, such as bass or linguistics, could enhance music and melody perception. Some studies added features that reduced enjoyment among people with normal hearing to determine if CI users could perceive these changes. However, the research demonstrated that a lack of perceptual accuracy does not preclude one from enjoying music. Given this, it may be prudent to examine appreciation by presenting melodies that are enhanced with music features accessible to CI users, rather than pursuing improvements in perception.

Several studies examined the features of music that reduce appreciation among patients with CIs. In the future, improvements in CI technology might correct these issues, enhancing music appreciation and therefore QOL. However, no standard reporting measure has been established for music appreciation among patients with CIs. This is reflected in the literature, as numerous publications describe heterogeneous outcome measures.

A limitation of this systematic review is the heterogeneity of data collected. The majority of studies were performed in soundproof booths. However, in 1 study, the setting was a concert for CI users in order to mimic natural listening conditions. Thus, applicability to real-life scenarios is difficult at the present time. Additionally, studies were inconsistent in handling patients with unilateral implantation. Alexander et al had subjects continue to use hearing aids in their nonimplanted ears, while other studies required the use of ear plugs in nonimplanted ears.

Outcomes ranged from musicality, naturalness, and pleasantness to pattern recognition, difficulty of perceiving melody, and timbre perception. Importantly, outcomes were different across most studies. While several studies opted for rating scales from 0 to 10, others used questionnaires, forced-choice paradigms, or complex melody recognition tests. Without a consistent protocol implemented across the studies and variable outcome measures, quantitative meta-analysis was not possible for this review.

Future studies are warranted to determine how to optimize the musical environment for CI users. Developing a standardized outcome-measuring tool, such as a uniform questionnaire or graded scale, should be developed and validated. This will improve preoperative counseling, temper patient expectations, allow better communication (among surgeons, clinicians, and audiologists), allow effective comparison among studies, and guide future research efforts. Other variables not examined in this review could affect music appreciation and enjoyment. These include the differences between patients pre- and postlingually deafened. Prior studies demonstrated no statistically significant difference in enjoyment between subjects with CIs in terms of pre- and postlingual deafness. Other areas for exploration include examining the effect of residual hearing on appreciation as well as music perception and enjoyment in the pediatric population.

The heterogeneous outcome measures identified in this systematic review suggest that rhythm and lyrics are important components of enjoyment, while CI users had difficulty with pitch and timbre perception. Because there is no standardized reporting metric for music appreciation among adult patients with CIs, a standardized validated outcome-measuring tool is warranted. Future studies are necessary to develop and validate a standardized outcome-measuring tool for CI users. This will aid in preoperative counseling, temper patient expectations, provide improved communication among clinicians, and guide future study.

Author Contributions
Phoebe E. Riley, conception of the work, drafting and revising the work, final approval, agreement to be accountable; Doug S. Ruhl, conception of the work, drafting and revising the work, final approval, agreement to be accountable; Macario Camacho, conception of the work, drafting and revising the work, final approval, agreement to be accountable; Anthony M. Tolisano, conception of the work, drafting and revising the work, final approval, agreement to be accountable.

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References


