World Journal of Otorhinolaryngology-Head and Neck Surgery (2021) 7, 116—125

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Review Article

Assessment of music experience after cochlear implantation: A review of current tools and their utilization

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Received 1 May 2020; received in revised form 24 November 2020; accepted 18 February 2021
Available online 3 April 2021

KEYWORDS
Cochlear implants;
Music experience;
Music perception;
Music enjoyment;
Assessment;
Tool

Abstract *Objective:* To provide an overview of the current available music assessment tools after cochlear implantation (CI); to report on the utilization of music assessments in the literature; to propose potential future directions in music assessment after CI.
Methods: A thorough search was performed in PubMed, Embase, and The Cochrane Library through October 31, 2020. MeSH search terms, keywords, and phrases included "cochlear implant," "cochlear prosthesis," "auditory prosthesis," "music," "music assessment," "music questionnaire," "music perception," "music enjoyment, and "music experience." Potentially relevant studies were reviewed for inclusion, with particular focus on assessments developed specifically for the cochlear implant population and intended for widespread use.
Results/conclusions: Six hundred and forty-three studies were screened for relevance to assessment of music experience among cochlear implantees. Eighty-one studies ultimately met criteria for inclusion. There are multiple validated tools for assessment of music experience after cochlear implantation, each of which provide slightly differing insights into the patients' subjective and/or objective post-activation experience. However, no single assessment tool has been adopted into widespread use and thus, much of the literature pertaining to this topic evaluates outcomes non-uniformly, including single-use assessments designed specifically for the study at hand. The lack of a widely accepted universal tool for assessment of music limits our collective understanding the contributory and mitigating factors applicable to current music experience of cochlear implantees, and limits our ability to uniformly evaluate the success of new implant technologies or music training paradigms.

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Peer review under responsibility of Chinese Medical Association.

Production and Hosting by Elsevier on behalf of KeAi

https://doi.org/10.1016/j.wjorl.2021.02.003

Introduction

Music is a universal part of the human experience that crosses geographic, linguistic, and cultural boundaries. However, up to a third of cochlear implantees report that they have stopped listening to music altogether, and decreased music perception, appraisal, and enjoyment are widely recognized findings among cochlear implantees.[1,2] Thus, many investigations have been conducted to better understand factors that influence music experience after cochlear implantation, such as speech outcomes, overall quality of life, pre-implantation musical experience, and post-implantation musical training on music enjoyment and appreciation.[2–7] Some factors identified are attributable to innate limitations of the cochlear implant (CI) device itself such as coding strategies and electrode design, whereas others are patient-related factors, such as transmission of signal from the CI to the auditory cortex and central deficits in integration of auditory stimuli.[8]

Despite the large volume of literature on this topic, there is no standard instrument for assessing music experience after cochlear implantation for use in research or in routine clinical practice.[9] Available assessment tools and outcomes measures are heterogenous in their scope, length, clinical feasibility, and extent of application in the literature, thereby limiting large-scale analysis of findings in this area across research groups and patient populations.[9] In this review, we discuss the current landscape of assessment tools for music experience after cochlear implantation, their development, and the extent of their adoption in the literature.

Methods

A thorough search was performed in PubMed, Embase, and The Cochrane Library through October 31, 2020. MeSH search terms, keywords, and phrases included "cochlear implant," "cochlear prosthesis," "auditory prosthesis," "music," "music assessment," "music questionnaire," "music perception," "music enjoyment," and "music experience." Potentially relevant studies were reviewed for inclusion.

Assessments included in this review were developed specifically for the assessment of music experience after cochlear implantation and with the intent for widespread research or clinical use. Assessments not initially developed for the cochlear implantee population but that have seen adoption in multiple studies evaluating music in CI users are detailed as well. Assessments not published in English-language literature were excluded. Tools and questionnaires developed for study-specific purposes were not included. Additionally, variants of reported assessments, such as a translated variant (eg the Dutch Musical Background Questionnaire) or a pediatric variant, will not be discussed in depth during this review.

Studies reporting on validation of primary assessments were reviewed for nature of music assessment (eg objective vs subjective measures), validation methodology, average length of administration, and nature of musical prompts or stimuli for objective testing, where applicable. Additionally, studies utilizing these assessments were reviewed for overall results, sample size of cochlear implantees, methodology, and discussion of the assessments themselves by primary authors.

Results

The initial search identified 4 699 articles, and after removing duplicates 643 studies were screened for relevance to assessment of music perception or experience among cochlear implantees. Three hundred and twenty-seven studies were excluded due to irrelevance to cochlear implantation or music assessment, being written in a non-English language, or including derivatives of published music assessment tools. Studies without clinical data, such as review papers, clinical trials with no associated publications, or commentary, were excluded, as were non-peer reviewed studies such as abstracts, oral presentations, or posters. Of the remaining 316 full-text articles, 235 studies were subsequently excluded for use of study-specific assessment tools, derivative assessment tools, or lack of music assessment tool usage. No additional studies were added after manually searching reference lists. Eighty-one studies ultimately met criteria for inclusion; 14 reported on development or verification of music assessments while 67 reported on their use in a clinical or research context (Fig. 1).

Overview of current available music assessment tools

Previously reported or validated tools developed in the United States include:

- Clinical Appreciation of Music Perception (CAMP; University of Washington)
- Appreciation of Music in Cochlear Implantees (AMICI; Columbia University)
- Primary Measures of Music Audiation (PMMA, Temple University)
- Multiple Stimulus with Hidden Reference and Anchor for Cochlear Implants (CI-MUSHRA; John Hopkins University)
- Iowa Music Perception and Appraisal Battery—Children's Version (IMPAB-C; University of Iowa)
- Music in Children with Cochlear Implants (MCCI; Johns Hopkins University)

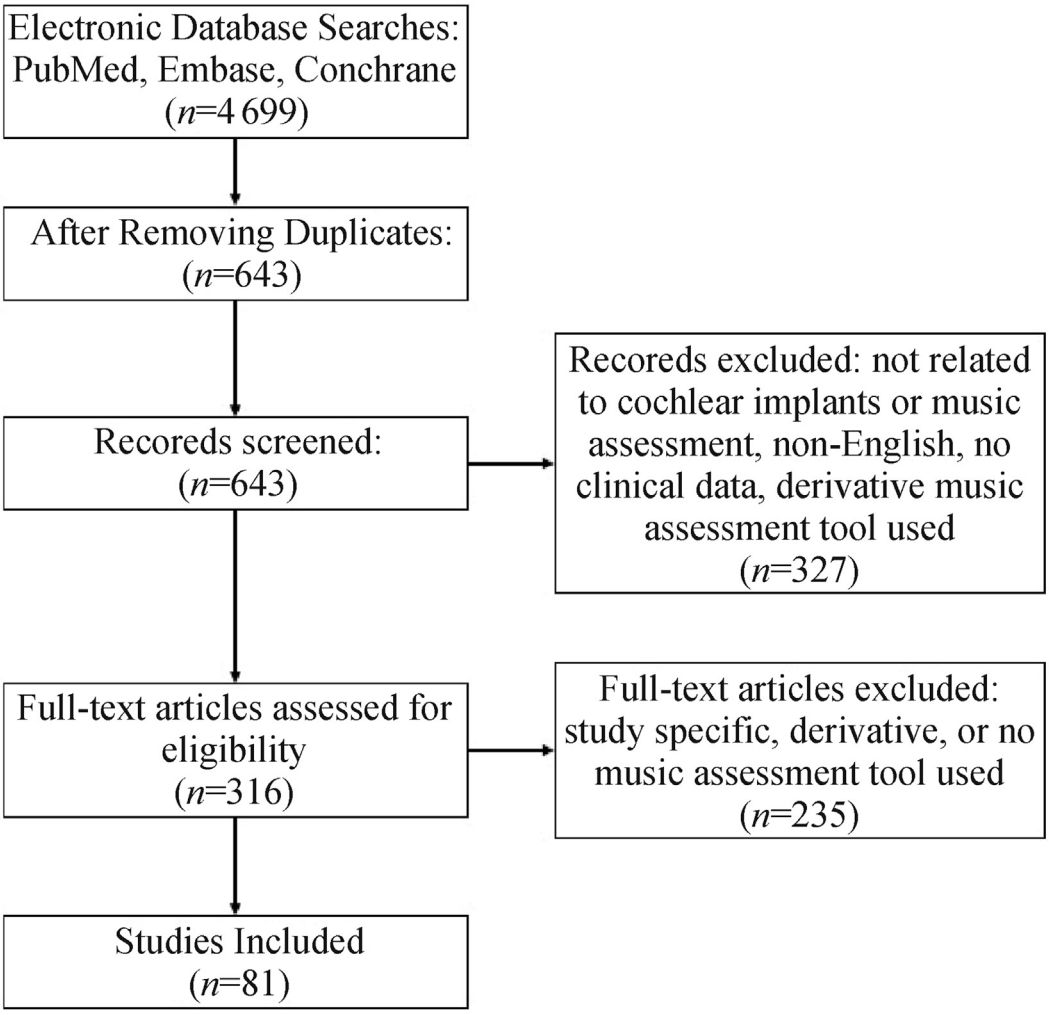

Fig. 1 PRISMA diagram.

- Iowa Musical Background Questionnaire (IMBQ; University of Iowa).[10–19]

Additional studies developed internationally include

- Musical Sounds in Cochlear Implants perception test (MuSIC; Technical University of Munich)
- Montreal Battery of Evaluation of Amusia (MBEA; University of Montreal)
- Music EAR (University of Toronto)
- Munich Music Questionnaire (MuMu; Technical University of Munich)
- University of Canterbury Music Listening Questionnaire (UCMLQ; University of Canterbury)
- Music-Related Quality of Life Questionnaire (MuRQOL; University of Southampton).[20–26]

An abbreviated summary of the validated assessments named, their respective components, and details regarding included objective musical stimuli is provided in Tables 1 and 2. In this section, we will report and discuss in detail the design and validation of each music assessment tool.

Objective music perception tests

Clinical appreciation of music perception (CAMP) test

The CAMP test was first reported in 2008, and involves 3 subtests evaluating pitch direction discrimination (identifying which note was higher), melody identification (ability to recognize a song), and timbre identification (ability to recognize an instrument).[10] The CAMP investigators explicitly designed this assessment to remove potential sources of bias native to the test itself. For example, stimuli presented in the pitch discrimination tasks became incrementally more difficult as the subject progressed, but the stimuli themselves were randomized in terms of directionality and base frequency (starting note). The melody identification task was presented in an isochronous fashion, which eliminates rhythm cues due to evidence that rhythm cues can confound melody recognition. Timbre identification was assessed with a standardized melody and with live instruments supplemented with pictures next to the name of the instrument.

The CAMP test was subsequently validated in a cohort of 42 cochlear implant subjects from the University of Washington with moderate to strong test-retest correlation.[11] Of

Table 1 Components of music appreciation assessments[11–16].

Item	CAMP	AMICI	MuSIC	MBEA	PMMA	CI-MUSHRA	Music EAR	IMPAB-C	MCCI	MuMu	UCMLQ
Pitch perception/Discrimination	X	–	X	X	X	–	X	–	X	–	–
Instrument identification/Timbre	X	X	X	–	–	–	X	–	X	–	–
Melody appraisal/Identification	X	X	X	X	X	–	X	X	X	–	–
Music/Noise discrimination or sound quality appraisal	–	X	X	–	–	X	–	–	–	–	–
Genre identification	–	X	–	–	–	–	–	–	–	–	–
Subjective musical experience/ Enjoyment/Quality of life	–	–	X	–	–	–	–	–	–	X	X
Music engagement	–	–	–	–	–	–	–	–	–	X	X
Music background	–	–	X	–	–	–	–	–	–	X	X

X: evaluation content of each assessment.

Table 2 Characteristics of stimuli for objective musical tasks.

Item	CAMP	AMICI	MuSIC	MBEA	PMMA	CI-MUSHRA	Music EAR	IMPAB-C	MCCI
Digital/Synthesized stimuli	X	–	–	X	X	X	–	–	X
Live stimuli	X	X	X	–	–	X	X	X	–
Familiar melodies	X	X	X	–	–	X	–	X	–
Test-specific melody	X	–	X	X	X	–	X	–	X

X: objective music stimulus information of each assessment.

note, however, difficulty was high for the CAMP test among CI users for both melody and timbre identification, with accuracy rates ranging from 15.7% to 48% for melodies and from 25.5% to 63.7% for timbre. By comparison, normal-hearing listeners had average accuracy of 72% for melody and 87% for musical instrument. It is important to note that with a 72% accuracy rate on melody identification, the isochronous format may have yielded significant difficulties even fors normal hearing listeners, tasked with identifying such familiar melodies as "Twinkle Twinkle Little Star," "Mary Had A Little Lamb," and "Rock-A-Bye Baby."

The CAMP has been utilized in a wide variety of settings by different research groups, including pediatric, hybrid CI, Australian, Turkish and Korean populations.[27–42] Notably, it has also been shown to have clinical feasibility in a large multicenter study involving 14 institutions and has been reported twice in longitudinal follow-up of patients after cochlear implantation.[43–45]

Appreciation of music in cochlear implantees (AMICI)

The AMICI was developed in 2008 with the explicit intent of developing a standard clinical music test to assess music perception and determine the effect of various processing strategies. To this end, the AMICI evaluates: (1) discrimination of music versus noise, (2) instrument identification, (3) musical style (genre) identification, and (4) recognition of musical pieces.[12] Instrument and genre identification are both closed-set stimuli, and musical piece identification is open set. The AMICI was subsequently shown to have high test-retest reliability in an adequately powered (0.9) assessment of thirteen CI subjects.[13]

Unlike the CAMP, the AMICI utilizes commercially available, royalty-free recordings lasting 20–30 s that are heard in daily life. The AMICI stimuli are not otherwise doctored to remove rhythm or lyrical cues. There are three forms available, each incorporating the four subtests as detailed above. Average performance among CI listeners was 97% for music versus noise, 70% (range 50%–89%) for instrument identification, 50% for genre identification (range 27%–98%), and 38% (range 6.25%–90%) for musical piece identification. Of note, a significant difference was noted in their validation cohort between subjects who reported musical training and those who did not. The authors further note that their use of commercially available stimuli render it an assessment that is specific to western musical culture. It has been subsequently utilized three times in research studies.[42,46,47]

Musical sounds in cochlear implants (MuSIC) perception test

The MuSIC perception test was first reported in 2013 and validated in 31 CI listeners unilaterally implanted with a Med-El Combi 40+/Pulsarci cochlear implant.[20] It comprises six objective and two subjective "modules," evaluating pitch discrimination, melody discrimination, chord discrimination, instrument detection, and instrument identification. Notably, the MuSIC perception test does not utilize synthesized instruments and thus includes 2800 musical files recorded from live instruments. It is a robust and lengthy test that averaged 90 min for completion for a given participant. Furthermore, it is designed such that an individual module can be utilized in isolation. In spite of the lengthy nature of this assessment, it has notably been cited and utilized in research assessing CI music outcomes based on age, in a pediatric population, for Mandarin-speaking adult CI users, in Germany, and in the UK.[48–63]

Montreal battery of evaluation of amusia (MBEA)

The MBEA was first published in 2003 with the goal of evaluating musical abilities after brain damage, such as stroke or resection, and to evaluate congenital amusia.[21] It

comprises of 6 tests: contour, interval, scale, rhythm, meter, and memory. Musical stimuli were 30 piano tones specifically produced for the test. For all tests but meter and memory, participants had to evaluate whether two stimuli were the same or different, with a total of 15 same and 15 different trials. Meter testing required participants to evaluate whether patterns were in march or waltz meter. Participants were not informed of the memory test, which incorporated 15 of the previously played phrases with 15 other new phrases and asked to discriminate if they had previously been played in the test. Overall scores were shown to have a normal distribution with sensitive test-retest reliability among 28 normal hearing listeners and was validated against Gordon's musical aptitude profile test. The MBEA takes about 90 min to complete.

The MBEA was then evaluated for use in a CI population in 2008 with 12 CI users.[22] All showed that users performed better on rhythm and meter tests than scale, contour, and interval tests, consistent with prior literature. However, the scale, contour, and interval tests were quite difficult for the CI, with users scoring just above chance. Additionally, the MBEA lacks a timbre test. Despite these limitations and its significant length, it has been utilized in research into pediatric populations as well as within Brazil, Canada and New Zealand.[42,64–72]

Primary measures of music audiation (PMMA)

The PMMA was first reported in 1979 as a music aptitude test for children aged 5 through 8, validated with 77 children from a community music school and 75 children in a private academic school against 873 children in the standardized group.[14] Each of the two subtests, rhythm and tone, had 40 pairs of music samples, and participants must determine for each pair whether the two samples are the same or different.

The PMMA was then evaluated for use in an adult CI population in 1991 with 18 CI users, and then 1992 with 34 CI users, after having been evaluated in hearing impaired children, adults with brain injury, and older adults.[15,73] The tonal subtest had greater internal consistency and mean discrimination index than the rhythm subtest, which CI users found quite difficult, suggesting that the rhythm subtest was not so suitable for use in the CI population. The tests took 40–60 min to complete. Despite this limitation, the PMMA was subsequently used in a pair of Spanish studies investigating music enjoyment after implantation in adults and one Australian study in children.[74–76]

Multiple stimulus with hidden reference and anchor for cochlear implants (CI-MUSHRA)

The CI-MUSHRA test was first reported in 2012 in 11 CI listeners as a strategy to numerically quantify sound quality among CI users and bridge the gap between perceptual accuracy testing and perceived sound quality testing.[16] A set of test stimuli is created by taking a series of systematically degraded versions and intermixing the original stimulus ("reference") and a highly altered version ("anchor"). Participants are then given the reference and are asked to assign to each version a sound quality rating between 0 (very poor) and 100 (excellent). The original studies looked at the effects of low frequency, high frequency, and reverberation but the assessment has also subsequently been used to evaluate the effectiveness of different programming strategies.[16,77–83] While heavily utilized within one research group, it has similarly not seen widespread adoption in the literature.

Music EAR

The Music EAR perception test was first reported in 2011 in a study with 12 CI listeners as a software program for diagnostic and rehabilitation purposes.[23] It comprises of two parts. The first uses musical excerpts of four different genres (country, jazz, classical, and popular) at three different complexity levels to assess music enjoyment. The second perception test had three subtests: "differentiating between five instrumental timbres", pitch pattern variation, and "identify target musical patterns embedded holistically in a single or multiple line melody." CI users underperformed normal hearing-non musicians, who subsequently underperformed normal hearing musicians, in all categories. Excerpts were 30–40 s each, and the entire test took CI users on average 61 min to complete. No subsequent studies were found utilizing this assessment tool.

Iowa music perception and appraisal battery–children's version (IMPAB-C)

The IMPAB-C was first reported in 2002 with 15 pediatric CI users as a pediatric version of an unpublished IMPAB, which itself was an attempt to improve upon the PMMA in an adult population.[17] Along with a musical background questionnaire, the two objective parts of the test are a song recognition test and a song appraisal test. For song recognition, participants heard 20 s samples of 9 songs and had to choose the correct option out of four possible options. For song appraisal, 45 song samples were played that included 10 classical songs and 20 non-classical (pop and rock) songs. No subsequent studies were found utilizing this assessment tool.

Music in children with cochlear implants (MCCI)

The MCCI was first reported in 2014 with 10 CI users and was designed specifically for music assessment in a pediatric population.[18] It takes inspiration from the PMMA and the pediatric version of the MBEA by folding a same/different task paradigm into a goal-oriented age-appropriate game. It comprises of five subtests: rhythm, pitch, melody, harmony, and timbre. Within each, five different pairs were presented in increasing order of difficulty with five same pairs distributed randomly throughout. The test uses standard sample instrument patches for each excerpt and takes about 45 min to complete. No subsequent studies were found utilizing this assessment tool.

Subjective music assessment questionnaires

Iowa musical background questionnaire (IMBQ)

The IMBQ is a 21-item questionnaire inclusive of multiple-choice questions, Likert scales, visual-analog scales, and open-ended questions. It was first reported in 2000 in 65 implant recipients participating in a survey of their musical background, experience with music prior to implantation, and experience with music after implantation.[19] The first draft of the questionnaire itself was developed from a questionnaire previously used by the investigators,[15] with

additional items included to expand the scope of the tool. The document was then evaluated by three audiologists and three implant recipients and edited for content and clarity. Lastly, the final questionnaire was formalized after review by two audiologists, three implant recipients, and four professionals involved in implant research and design. Its subsequent use in the literature has been primarily by the publishing group to quantify musical background of participants, but was used in one Spanish study.[84–86]

Music related quality of life (MuRQOL) questionnaire

The MuRQOL is a relatively recent developed test, reported in 2017 with the explicit aim to assess music rehabilitation with design for repeated assessment over time.[26] There is no objective component to this assessment tool. A preliminary instrument was first developed in collaboration with 24 experts, then completed by 147 adult CI users before undergoing refinement with psychometric techniques for reliability, item selection, and structural definition. It encompasses two domains of music perception and engagement, each assessing 18 items and their relative importance. No subsequent studies were found utilizing this assessment.

The munich music questionnaire (MuMu)

The MuMu was first published in 2002 with 103 primarily Combi 40/40+ users in Germany.[24] It was developed in conjunction with CI users, musicians, a musicologist, and a statistician, and piloted in 32 implant users from two centers. Its 25 questions include those about present music activities, musical background, musical preference, and subjective assessment of music perception assessed using multiple choice questions and Likert scales. Notably it has been utilized in German, Swiss, Spanish, Brazilian, and Chinese studies.[56,57,87–92]

The university of canterbury music listening questionnaire (UCMLQ)

The UCMLQ was first published in 2010 with designing a music training program in mind.[25] In-person interviews were conducted with three higher performing CI recipients with musical experience and interest; after pilot-testing on nine CI recipients, 221 questionnaires were distributed with 100 responses. The UCMLQ has 48 questions divided into seven sections: music listening and musical background, sound quality, musical styles, music preferences, music recognition, factors affecting music listening enjoyment, and music training program.

Completing the questionnaire took about an hour. Differing from other questionnaires, participants were asked to rate how music sounds with a CI compared to how they expect it to sound to a personal with normal hearing. This group subsequently utilized the UCMLQ to investigate the impact of prelingual vs. post lingual implantation and hearing aid use on music experience.[92]

Discussion

Utilization of music assessments in the literature

To date, there is no single music assessment that predominates in relevant areas of research. Many assessments have been primarily used by the developing research team and did not end up being widely adopted, despite being designed for such adoption. Objective assessments that have been the most widely adopted in the research setting are the CAMP (21 papers, 8 distinct research groups), MuSIC (18 papers, 9 distinct research groups), and MBEA (10 papers, 6 distinct research groups).

Each of these objective assessments have limitations worthy of discussion. The MuSIC test is a lengthy test averaging 90 min for administration. CI users had great difficulty with the melodic and timbre subtests of the CAMP and the melodic (scale, contour, interval) subtests of the MBEA, suggesting an inadequate discrimination index in these test portions for CI users. For subjective assessments the MuMu is the most widely adopted subjective assessment analyzed in this paper (8 studies, 6 distinct research groups).

It is also worth noting that even with a multitude of tools to use, many research investigations still choose to develop their own. In a recent systematic review of objective evaluations of music appreciation after cochlear implantation in adults, more than two-thirds (13/18 studies) utilized assessment measures developed solely for that investigation.[9] This lack of a standardized assessment tool for outcomes reporting has limited large-scale analysis of findings in this area of research.[9] It is not known whether our current accepted knowledge with regard to the CI music experience apply universally to all users; conversely, it is not known on a large scale whether there are implant-specific or patient-specific factors that reliably yield improved outcomes in certain aspects of post-CI music perception and enjoyment.

An additional difficulty in interpreting the large volume of literature in the field is the discrepancy between the modern cochlear implantee population and the CI users that have been studied. Expanding indications for cochlear implantation and technological advances have rendered the cochlear implant population more heterogenous and larger in absolute size. Yet, studies developing these assessment tools for or applying them to a CI population have been on relatively small populations. Objective assessment tools detailed in this study were trialed on an average of 19.8 CI users (st. dev 12.3, range 10–42). Similarly, some conclusions regarding CI users' music experience that are accepted as fact are based on findings from detailed studies performed in smaller populations and with limited longitudinal follow-up, particularly with respect to objective metrics. Fifty-eight percent (22/38) of investigations of CI listeners cited in a 2012 review of music appreciation and training encompassed a CI-listener sample size less than 25 (Fig. 2).[2] The cause of this is likely multifactorial, but one possible contributing factor is the length of testing, with some assessments such as the MuSIC and MBEA tests requiring up to 90 min to complete.

Despite a large volume of literature on this topic and such studies stated goals to be used clinically as well, these validated studies have yet to be incorporated into widespread routine clinical use for assessment of music experience after implantation. One large multi-center clinical evaluation of music experience involving 145 CI users across 14 North American clinics led investigators to conclude that the "CAMP and IMBQ are feasible for routine clinical use,

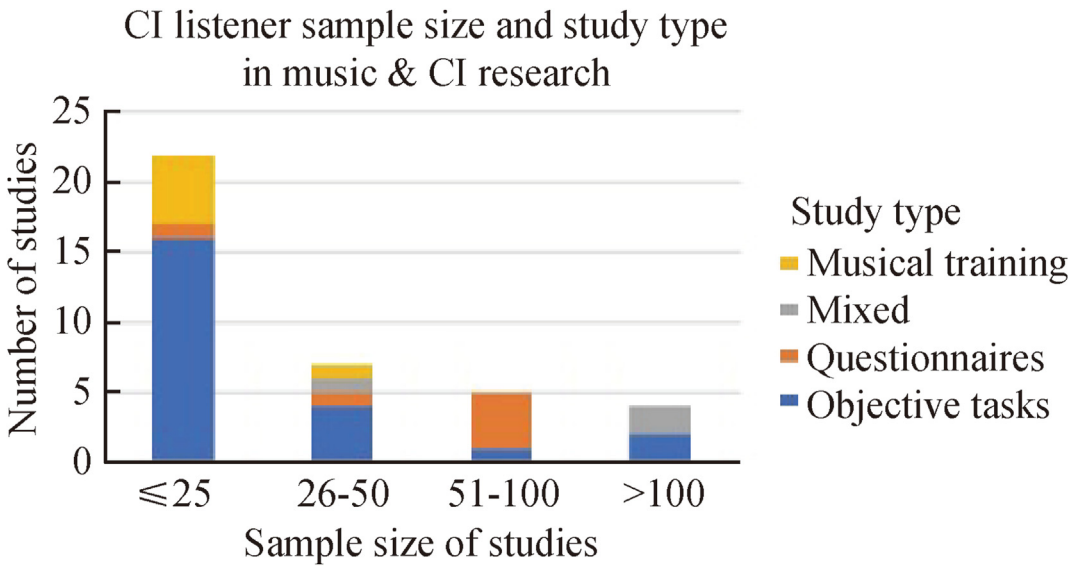

Fig. 2 Distribution of CI-listener sample size and study type in a 2012 review of music appreciation by Looi et al[2].

providing results consistent with previous thorough laboratory-based investigations."[40] Indeed, the CAMP has been used clinically in two studies: to track outcomes for 50 hybrid CI users for up to one year post implantation as well as track outcomes for 27 Korean CI users up to four years post-implantation (mean 38.6 ± 18.7 months).[41,42] The IMBQ, on the other hand, has not seen such utilization.

It is interesting to note that the most clinical use reported has been of the CAMP, whose average 30 min administration time is among the shortest of the included tests. This suggests it is also likely that length of testing has impeded widespread clinical adoption. After all, a routine music assessment would further lengthen audiology visits that already include thorough assessments of impedances, electrode stimuli response, and of course, speech testing. This is compounded by the fact that while each of tool provides a unique and in-depth understanding of individual aspects of an implant user's music experience, to date, there is no single validated tool that provides a comprehensive, subjective and objective assessment of the patient's overall music experience after CI.[9] One would therefore need to administer multiple studies, placing an increased time burden onto the clinical encounter.

Future directions

In the interests of furthering our understanding of music appreciation and assessing the potential impact of new developments, we propose the development and validation of a shortened assessment in the interest of clinical feasibility. We acknowledge that abbreviated testing will necessarily come at the cost of depth and breadth of that test. Furthermore, we recognize the innate challenges of designing an appropriate test that adequately captures the spectrum of experience while maintaining sufficient brevity to be realistically incorporated into a routine clinic visit.

Some would reasonably question whether current knowledge regarding music appreciation, both in terms of natural history and impact of any proposed intervention, is sufficiently detailed to begin work on a shortened music assessment. However, we postulate that insufficient widespread adoption of existing assessments has precluded large-sample longitudinal assessment of how various measures of music appreciation change over time after cochlear implantation. Additionally, the lack of a standardized reporting metric limits our assessment of how various interventions may alter these measures of music appreciation.

A shortened assessment can still be sufficiently comprehensive to evaluate multiple domains of music appreciation. Current assessments are methodically thorough; there is yet potential for improving the efficiency of existing approaches, thus adjusting the depth of these assessments without sacrificing the breadth. We believe that the most salient metrics can be captured in a clinically practical test that provides an accurate global overview of how a CI user's "musical status" compared to their peers for patients and clinicians alike, not unlike a speech recognition test. By prioritizing feasibility over depth, we believe that our tool can be integrated into routine clinical follow-up for CI patients. This could not only improve our understanding of the "natural history" of music experience after implantation, but also standardize our evaluation of any current or future interventions intending to improve that experience. Longer, validated assessments will remain critical resources for in-depth assessments of specific domains of music appreciation and in specific, smaller populations of interest. We suggest that such a tool assesses objective and subjective music-related CI experience, is structured for repeated assessment over time, and is clinically feasible for routine use both in length of assessment and interpretability of results.

Conclusions

Despite an extensive and respectable body of work dedicated to the development and validation of music

assessments after cochlear implantation, no single test has been adopted into widespread use in research or clinical context. Current assessments evaluate a variety of metrics, but only one combines subjective and objective metrics into a single, albeit lengthy, test. A preponderance of work assessing music experience after cochlear implantation are based upon unvalidated assessments developed for the purposes of an individual study. In order to promote a unified approach to research and clinical evaluation, we propose the development and validation of a clinical feasible assessment tool incorporating metrics of both subjective and objective music experience after cochlear implantation.

Statement of ethics

This study complies with internationally-accepted standards for research practice and reporting.

Funding sources

There were no funding sources applicable to this study.

Author contributions

All three authors have met the four criteria for authorship as laid out by the ICMJE. Specific contributions are noted as follows:
Dr. Tiffany Peng Hwa: Manuscript preparation of original draft, literature analysis, development of tables and figures.
Dr. Michael J. Ruckenstein: Conceptualization, supervision of all activities and intellectual direction, manuscript revision for intellectual content.

Financial disclosures

None.

Declaration of competing interest

The authors of this study have no financial or personal conflicts of interests to disclose. No human or animal subjects were involved in this research. This writing is free from bias and contains no assumptions about the beliefs or commitments of any reader.

Acknowledgements

None.

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Edited by Li-shi Yang