MUSIC & COCHLEAR IMPLANT
SYMPOSIUM

Program of the 3rd International

# Music & CI Symposium

Cambridge Hearing Group
September 15th – 16th, 2021

Cambridge Hearing Group

William Demant Foundation

UNIVERSITY OF CAMBRIDGE

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# Contents

# Preface

## Cambridge Hearing Group

The Cambridge Hearing Group (CHG) comprises over 30 hearing researchers across two Universities and a major teaching hospital in Cambridge. Our collaborations within Cambridge enable us to have a clear pipeline for research activities to flow between the lab and the clinic. There are unusually strong links between academic researchers and clinical partners at Addenbrookes hospital and in the private hearing sector. We have a strong network of collaborators in the UK, Europe, North America, Canada and Australia.

Current major research themes include cochlear-implant research, from front-end signal processing to objective measures of neural health, neuroplasticity in normal and hearing-impaired listeners, binaural processing, music and pitch perception, training to optimise hearing, the effects of hearing loss throughout the lifespan, and both physical and computational models of hearing.

The group benefits from a wealth of world-class expertise in psychology, neuroscience, engineering, surgery, speech science, audiology, auditory physiology, electrophysiology, material science, and computer science. We use a wide variety of research tools to produce cutting-edge research. These include psychoacoustics, virtual reality, speech perception, web-based data collection, objective measures such as EEG, biophysical and computational models of the inner ear, cadaveric studies, clinical models, and paediatric studies.

## Oticon Medical

*Because sound matters*

Oticon Medical is a global company in implantable hearing solutions, dedicated to bringing the world of sound to people at every stage of life. As a member of one of the world's largest groups of hearing healthcare companies, we share a close link with Oticon and direct access to the latest advancements in hearing research and technologies. Our competencies span more than a century of innovations in sound processing and decades of pioneering experience in hearing implant technology.

By working collaboratively with patients, physicians and hearing care professionals, we ensure that every solution we create is designed with user needs in mind. We share an unwavering commitment to provide innovative solutions and support to enhance the quality of life for people, wherever life may take them, because we know how much sound matters.

# Introduction

## Scientific Committee

**Debi Vickers,** Principal Research Associate, Department of Clinical Neurosciences, Cambridge Hearing Group
**Bob Carlyon,** Deputy Director of the Medical Research Council (MRC), Cognition and Brain Sciences Unit, Cambridge Hearing Group
**Brian Moore,** Professor in Auditory Perception, Auditory Perception Group | Department of Psychology, Cambridge Hearing Group
**Ian Winter,** Senior Lecturer, Department of Physiology, Development, and Neuroscience, Cambridge Hearing Group
**Manohar Bance,** Professor of Otology and Skull Base Surgery, Department of Clinical Neurosciences, Cambridge Hearing Group

## Organizing Committee

**Aswin Wijetillake,** Translational Research Manager, Research & Technology Development, Oticon Medical
**Kathleen Faulkner,** Clinical Research Study Coordinator, Research & Technology Development, Oticon Medical
**Alan Archer-Boyd,** Post-doctoral researcher, Cambridge Hearing Group
**John Deeks,** Senior Scientist, Cambridge Hearing Group
**Giorgos Dritsakis,** Post-doctoral researcher, Cambridge Hearing Group
**Charlotte Garcia,** PhD student, Cambridge Hearing Group
**Tobias Goehring,** Post-doctoral fellow, Cambridge Hearing Group
**Cynthia Lam,** PhD student, Cambridge Hearing Group
**Marina Salorio-Corbetto,** Post-doctoral researcher, Cambridge Hearing Group
**Ben Williges,** Post-doctoral researcher, Cambridge Hearing Group
**Bhavisha Parmar,** Post-doctoral researcher, Cambridge Hearing Group
**François Guérit,** Post-doctoral fellow, Cambridge Hearing Group
**Carolina Leal,** PhD student, Cambridge Hearing Group

## Advisory Committee

**Charles Limb,** Francis A. Sooy Professor of Otolaryngology-Head & Neck Surgery, Chief of Otology, Neurotology, and Skull Base Surgery, University of California, San Francisco (UCSF)
**Jeremy Marozeau,** Associate Professor, Hearing Systems Group, Center for Applied Hearing Research, Technical University of Denmark (DTU)
**Søren Kamaric Riis,** Chief Research Officer, Research & Technology Development, Oticon Medical

## Music and Cochlear Implants Symposium

Cochlear Implants have proven to be a very effective treatment for severe to profound hearing loss and today there are more than 800,000 patients using a cochlear implant worldwide. While the majority of people using a cochlear implant achieve good speech perception in quiet, many adults experience poor music perception. Both self-reported levels of music enjoyment and measured discrimination of fundamental features in music are significantly lower than in normal hearing adults. Decades of research and product development on cochlear implant signal processing, stimulation and rehabilitation have focused mainly on speech sounds and little on music listening and enjoyment.
The poor music “delivery” in current cochlear implants stands in stark contrast to the general understanding that music is an important part of human well-being and quality of life. Recent scientific evidence points at music as an important auditory input for the development of the human brain – both in terms of cognitive, emotional and auditory processing abilities. Similarly, throughout time and across cultures, music has always played an important role in social gatherings, such as listening to music with friends, singing in the church or going to live music events, these activities can sometimes be unpleasant for people with cochlear implants.

There is no doubt that music is an essential part of social life, health and general well-being – and that substantial research is still needed to give hearing-impaired people better access to this dimension of life.

We are therefore delighted to bring together researchers, clinicians, and people using cochlear implants from across the globe to join forces on bringing music to people with cochlear implants.

# Practical Information: In-Person Event

### Symposium Venue
The symposium will take place at:

**St John’s College in Cambridge, UK**

| | |
|---|---|
| Address: | St John's Street, Divinity School – https://map.cam.ac.uk/Divinity+School#52.207820,0.118285,17 |
| Postcode: | CB2 1TP |
| Location: | Cambridge |
| Country: | United Kingdom |
| Telephone: | +44 1223 338600 |
| Website: | https://www.joh.cam.ac.uk/ |

*Few other venues can provide the sense of occasion that you'll find at St John's College, with impressive architecture steeped in history, and the beautiful surroundings of the sweeping College grounds.*

The symposium has been co-funded by the William Demant Foundation and will be free for attendees.

### Dinner & Music Event
A complimentary dinner & musical event will be held during the evening of the first day of the symposium, and will take place at:

**St. John’s College Hall**

*‘The Hall’ is a magnificent 16th century building with a hammerbeam roof and fine old linenfold paneling, located in St John’s College.*

The evening will be an occasion to enjoy a great meal and socialize with your colleagues.

### Weather
“There's no such thing as bad weather, only unsuitable clothing.”

While the UK does experience four separate seasons, light showers and cloudy skies are prevalent throughout the year. Daily highs range from 9°C (48°F) in the winter to 23°C (73°F in the summer, and weather conditions can fluctuate quite a bit over the course of a day. Summers in Cambridge are generally mild and pleasant, but not without occasional rain showers. Days are long with high temperatures around 21°C (70°F) to 23°C (73°F) degrees and lows around 15°C (59°F). While you can leave the winter wear at home, we recommend packing a light jacket, raincoat, and/or sweater for chilly summer evenings.

https://www.wunderground.com/weather/gb/cambridge

### Languages
English is the primary language spoken in the UK.

### Currency
Britain’s national currency is the pound sterling (symbol: £)

## The Dinner & Music Event
St. John's College Hall


# Programme

## Wednesday Sep. 15th 2021

| | | |
|---|---|---|
| 09:00 | | Registration |
| 09:20 | Opening Session | Welcome |

### Pitching it Right: Exploring Melody

| | | |
|---|---|---|
| 9:30 | Bob Carlyon | Rhythm and Blues: what CI listeners can get out of music |
| 09:55 | Nille Kepp | Differences and similarities in pitch discrimination and timbre recognition between Danish children with bilateral hearing aids or bilateral cochlear implants and children with normal hearing. |

### Mixing it Up: Listening Approaches for Enjoying Music I

| | | |
|---|---|---|
| 10:10 | David Landsberger | How music perception is influenced by the combination of acoustic and electric stimulation in single-sided deafened listeners |
| 10:35 | Aaron Hodges | Evaluation of CI mediated music processing using electrodogram mapping to compare with perception |
| 10:50 | **Break** | |

### Mixing it Up: Listening Approaches for Enjoying Music II

| | | |
|---|---|---|
| 11:20 | Mark Fletcher | Enhancing music perception in CI users by providing missing sound-information through tactile stimulation |
| 11:45 | Tushar Verma | Audio-tactile interaction in timbre: Effect of tactile stimulation on auditory temporal envelope perception |
| 12:00 | Katelyn Berg | Can we improve music perception and appreciation using strategic apical electrode deactivation? |
| 12:15 | Poster pitches | |
| 13:15 | **Lunch** | |

### Raising the Bar: Signal Processing Advances and Settings for Improved Music Listening

| | | |
|---|---|---|
| 14:15 | Brian Moore | Listening to music through hearing aids: potential lessons for CIs |
| 14:40 | Waldo Noguiera | Signal processing and sound coding strategies to make music more accessible for CI users |
| 15:05 | Johannes Gauer | Can spectral complexity reduction improve music perception in CI users? |
| 15:20 | René Gifford | Benefits of combining electric and acoustic hearing for music sound quality and various aspects of music perception |
| 15:45 | **Break** | |
| 16:15 | Sina Tahmasebi | Optimized CI fitting to enhance singing voice in popular music |
| 16:30 | Charles Limb | Tuning CIs using CT-based pitch mapping |
| 16:55 | Kate Gfeller | **Cochlear Implant User Panel**<br>Thinking outside the booth: Insights from CI users about music engagement in everyday life, and implications for research and clinical guidance |
| 18:00 | Jeremy Marozeau, Charlotte Nordin, Raphael Ortis | **Social Night:** An audio-tactile artistic installation to enhance musical experiences |
| 18:30 | Close, followed by dinner and music event | |

# Programme

## Thursday 16th Sept 2021

### Practice Makes Perfect: Training Approaches, Benefits and Limitations I

| | | |
|---|---|---|
| 09:00 | Colette McKay | Does music training have a role in CI (re)habilitation? |
| 09:25 | Ritva Torppa | How music training and singing improves the speech and language skills of children with hearing loss – MULAPAPU-project |
| 09:40 | Deniz Başkent | Can music training improve vocal emotion perception in CI users? If yes, what kind? |
| 10:05 | Céline Hidalgo | Rhythmic training: an effective tool for children with cochlear implants |
| 10:20 | Lorenzo Picinali and Yuli Levtov | Improving music listening for bilateral CI users using immersive audio and VR-based applications |
| 10:45 | **Break** | |

### Higher Order Processing: Brain Mechanisms that Underpin Music Listening

| | | |
|---|---|---|
| 11:15 | Peter Vuust | The musical mind that predicts |
| 11:40 | Chi Yhun Lo | Social wellbeing and the role of music for children with hearing loss |
| 11:55 | Niki Vavatzanidis | Discriminative abilities of young children in music one and two years after cochlear implantation: an EEG study |
| 12:10 | Poster pitches | |
| 13:00 | **Lunch** | |

### Sponsor Session: Oticon Medical's Take on Music & CI

| | | |
|---|---|---|
| 14:00 | Manual Segovia Martinez | Development of next generation CI coding strategies |
| 14:15 | Marianna Vatti | Effect of frequency-to-electrode allocation manipulations on music features predicted with objective measures |
| 14:30 | Scott Aker | Effect of audio-tactile congruence in vibrotactile music enhancement for cochlear implant users |

### Practice Makes Perfect: Training Approaches, Benefits and Limitations II

| | | |
|---|---|---|
| 14:45 | Ian Cross | Exploring spontaneous interaction in speech and music and the extent to which common interactive processes underlie both "domains" |
| 15:10 | Cilia Beijk and Joke Veltman | Musi-CI training: hearing training from a musical perspective by and for Cochlear Implant users and how to fit this into regular CI rehabilitation. |
| 15:25 | Ruth Mallalieu | Factors influencing music engagement in everyday lives of pediatric cochlear implant users |
| 15:40 | Debi Vickers | Maximising engagement and effectiveness of training |
| 16:00 | Closing remarks | |
| 16:30 | **End of Symposium** | |

**Presenter:** Deniz Başkent

**Title:** Can music training improve vocal emotion perception in cochlear implant users? If yes, what kind?

**Affiliations:** dB SPL Lab, University of Groningen

**Abstract:** At dB SPL Lab of University of Groningen, we run a number of projects on music and cochlear implants. In some of these projects we explore potential therapeutic effects of music therapy and music training for cochlear-implant users. One part of our interest comes from the potential transfer of training from music activities to improvement of general listening abilities, especially for speech understanding in noise. For example, in addition to many other studies, our previous research has shown that musicians may not only have advantages in music perception, what they are trained for, but perhaps also in better understanding speech in background speakers, a transfer of training effect (Başkent and Gaudrain, 2016 JASA-EL; Kaplan et al., 2021 Frontiers). Additionally, we are also interested in any potential positive effects music therapy or training may provide on the overall quality of life. At least one study indicated a potential connection between vocal emotion recognition and quality of life in adult implant users (Luo et al, 2018 JASA-EL).

In a previous study from our lab (Fuller et al, 2018 Trends in Hearing), we have explored various approaches to music training (music therapy, computerized music training) and various perception tests (music, speech, and vocal emotion perception) in implant users. The different training approaches seemed to offer different (and limited) benefits. In summary, both music therapy and training produced no improvement for speech perception or general measures of quality of life, but music training improved some aspects of music perception, a direct training effect, and music therapy improved vocal emotion perception, a transfer of training effect. The participants also subjectively reported that they felt they gained benefits from training. Currently we are exploring different ways of quantifying vocal emotion perception, for example, using non-linguistic affective speech materials (EmoHI; Nagels et al, 2019 VIHAR) or emotional music pieces, to further identify music training improvements in this domain.

**Presenter Bio:** Deniz Başkent is a professor in Audiology group of University Medical Center Groningen (UMCG), University of Groningen, Netherlands. Coming to the medical school via the routes of electrical engineering, robotics, and biomedical engineering, and also via both academic and industry experiences, provided great opportunities for clinical research. Being able to use technical expertise and approaches to clinical problems has been a wonderful opportunity and made the Speech Perception Lab (dB SPL) flourish in both fundamental and applied projects, all aimed at increasing quality of life of individuals with hard of hearing. Deniz also loves singing, especially with others in a band or choir. Wanting to share all the positive feelings and learning experience Deniz acquired from own music activities has led to a number of research projects looking into music experience with cochlear-implant listening. What Deniz and dB SPL lab would like to know is, how can we make music experience more pleasant for implant users, and how can we benefit from it in improving quality of life for implant users.

1. Başkent, D, Fuller, C, Galvin III, J, Schepel, L, Gaudrain, E, Free, R, 2018. Musician effect on perception of spectro-temporally degraded speech, vocal emotion, and music in young adolescents. J Acoust Soc Am EL 143, EL311-EL316.
2. Kaplan, EC, Wagner, AE, Toffanin, P, Başkent, D, 2021. Do musicians and non-musicians differ in speech-on-speech processing? Frontiers in Psychology, section Auditory Cognitive Neuroscience 12:623787.
3. Luo, X, Kern, A, and Pulling, K.R., 2018. Vocal emotion recognition performance predicts the quality of life in adult cochlear implant users. J Acoust Soc Am EL 144, EL429-EL435.
4. Fuller, C, Galvin III, J, Maat, A, Başkent, D, Free, R, 2018. Comparison of two music training approaches on music and speech perception in cochlear-implant users. Tr Hearing 22, 1-22.
5. Nagels, L, Gaudrain, E, Vickers, D, Lopes, MM, Hendriks, P, Başkent, D, 2019. Vocal emotion recognition in school-age children: normative data for the EmoHI test. PeerJ Preprints e27921v1. Presented at VIHAR 2019.

**Presenter:** Bob Carlyon

**Title:** Rhythm and Blues: what cochlear implant listeners can get out of music

**Affiliations:** Cambridge Hearing Group, MRC Cognition & Brain Sciences Unit, Cambridge, U.K.

**Abstract:** In this presentation I will review some of the cues that are important for music perception, how they are preserved in the electrical pattern of stimulation on each electrode (the "electrodogram"), and the fidelity with which these cues are processed by cochlear implant (CI) listeners. Cues relevant to the timing, duration, and intensity of notes and other music sounds are important for the perception of rhythm, and, at least when not masked by other sounds, are well-preserved in the electrodogram. They are likely to provide information at the level of the auditory nerve (AN) that is broadly similar to that occurring in normal acoustic hearing (NAH), and are generally perceived accurately by CI listeners. Differences in the attack and decay times of individual notes are also fairly well-preserved in the electrodogram and can support the perception of differences in timbre.

Similar to the spoken word, song lyrics can be perceived using the coarse spectral and temporal cues that are preserved in the electrodogram, and coarse changes in timbre produced by, for example, shifts in the spectral centre of gravity or in spectral tilt are likely to be well-preserved. In contrast, the coding of fundamental frequency, which is the physical correlate of pitch, is degraded by CI speech processing algorithms at the level of the electrodogram. Furthermore, direct stimulation experiments, which bypass the clinical speech processor and can present idealised information to one or more electrodes, reveal a biological limitation: even with these idealised stimuli pitch perception is much worse than in NAH, and deteriorates dramatically as the fundamental frequency increases above about 300 Hz. Hence although CI listeners may enjoy rhythm, music perception that depends primarily on the perception of pitch and melody is likely to give CI listeners the blues. I will review the nature of the limitations in pitch perception by CI listeners, review the success (or otherwise) of attempts to overcome these, and consider the prospects for improving pitch and melody perception in the next generation of CIs.

**Presenter Bio:** Bob Carlyon has been studying hearing since his PhD in Cambridge in the early 1980s, studying intensity discrimination in normal-hearing listeners. He subsequently spent a year at Northeastern University before returning to Sussex University (Brighton, UK) as a Royal Society University Research Fellow in 1988. He moved to the MRC Cognition & Brain Sciences Unit in 1994, where he is currently Deputy Directo. Much of Bob's research has involved the study of the basic auditory processes involved in auditory scene analysis, combined with a study of how they interact with cognition. Over the last 20 years his research has increasingly focussed on understanding and improving hearing by cochlear implant listeners.

**Presenter:** Ian Cross

**Title:** Exploring spontaneous interaction in speech and music and the extent to which common interactive processes underlie both "domains"

**Affiliations:** University of Cambridge

**Abstract:** Music generally suffers in any comparisons with language; as a sonic domain made up of complex patterns that can elicit aesthetic or hedonic responses, its uses seem limited and its significance appears inconsequential. But music is not just intricate configurations in sound that can make us feel good; music, like language in the guise of speech, is also a participatory and multimodal medium for communicative interaction with diverse and significant functions. Participatory music displays features and involves processes that equip it to manage social relations by inducing a sense of mutual affiliation between participants. At least some of those features and processes are present in other modes of human interaction, particularly those genres of speech concerned with establishing or continuing mutual affiliation or attachment, generally termed "phatic". I propose that music as an interactive medium intersects so significantly with speech in the phatic register as to be indistinguishable from it. This paper will survey evidence that supports this proposal, from ethnomusicology, linguistics, and from recent research at Cambridge into spontaneous interaction in speech and music, and explores some of its implications for the communicative and social experience of cochlear implant users.

**Presenter Bio:** Ian Cross is based in the Faculty of Music at the University of Cambridge, where he is Professor and Director of the Centre for Music and Science. His early work helped set the agenda for the study of music cognition; he has since published widely in the field of music and science, from the psychoacoustics of violins, through the evolutionary roots of musicality, to the effects of group music-making on the development of children's empathic capacities. The two main strands of his current research involve testing ways of making musical notation easier to read at sight, and the experimental investigation of common processes that underlie interaction in speech and in music. He is Editor-in-Chief of SAGE's new Open Access journal Music & Science, is a Fellow of Wolfson College, Cambridge and is also a classical guitarist.

**Presenter:** Mark D. Fletcher

**Title:** Enhancing music perception in cochlear implant users by providing missing sound-information through tactile stimulation

**Affiliations:** University of Southampton Auditory Implant Service, Faculty of Engineering and Physical Sciences, University of Southampton, University Road, Southampton, SO17 1BJ, United Kingdom[1]

Institute of Sound and Vibration Research, Faculty of Engineering and Physical Sciences, University of Southampton, University Road, Southampton, SO17 1BJ, United Kingdom[2]

**Abstract:** Cochlear implants (CIs) are remarkably effective at restoring hearing in severely-to-profoundly hearing-impaired individuals. However, users often struggle to deconstruct complex auditory scenes, which can lead to reduced music enjoyment and impaired speech understanding in background noise. Several recent studies have shown that haptic stimulation can enhance CI listening by giving access to sound features that are poorly transmitted through the electrical CI signal. This "electro-haptic stimulation" improves melody recognition and pitch discrimination, as well as speech-in-noise performance and sound localization. This talk will discuss the current evidence that haptic stimulation can enhance music perception in hearing-impaired listeners. This will include an assessment of the evidence of enhanced music enjoyment by current haptic devices and a discussion of which key sound features can be effectively transmitted through haptic stimulation. Finally, ongoing and future work in this area will be discussed, including new haptic devices and signal-processing strategies. It will be argued that there is huge potential for haptic devices to enhance music perception in CI users.

**Acknowledgements:** The speaker's salary is funded by the William Demant Foundation.

**Presenter Bio:** Mark Fletcher is a Senior Research Fellow at the Institute of Sound and Vibration Research and University of Southampton Auditory Implant Service. He leads the Electro-haptics Research Project, which focuses on improving hearing in cochlear implant users by presenting missing sound-information through vibration on the skin. Mark also leads a related project involving the development of a virtual acoustics system for use in clinical and research facilities and for remote training and testing. In addition, Mark co-created the RealSpeech auditory training app, which focuses on the recreation of highly realistic listening environments and is currently part of a UK-wide trial as part of the CHOICE remote care platform.

Before working at Southampton, Mark did his PhD at the Institute of Hearing Research, where he used auditory psychophysics and otoacoustic emissions to help develop methods for measuring top-down control of cochlear processing in humans. Following this, Mark was involved in the Health Effects of Ultrasound in Air (HEFUA) project at Southampton, which investigates potential adverse health effects caused by very high-frequency sound and ultrasound.

[ais.southampton.ac.uk/](ais.southampton.ac.uk/)
[www.southampton.ac.uk/engineering/research/centres/isvr.page](www.southampton.ac.uk/engineering/research/centres/isvr.page)
[www.electrohaptics.co.uk](www.electrohaptics.co.uk)

**Presenter:** Kate Gfeller

**Title:** Thinking outside the booth: Insights from cochlear implant users about music engagement in everyday life, and implications for research and clinical guidance

**Affiliations:** School of Music & Dept of Communication Sciences and Disorders, University of Iowa

**Abstract:** The topic of music and cochlear implants is complex and multifaceted. We know that music perception and engagement is challenging and often unsatisfactory for many CI users. However, there is considerable variability within the population. Some CI users have attained remarkable enjoyment of and engagement in music experiences, though this phenomenon is not fully understood. A thorough understanding requires multidisciplinary perspectives and a variety of investigatory approaches. Much of our current understanding comes from laboratory research focusing on CI technology, audition, and neuroplasticity in relation to the complex auditory signal of music. A complementary source of information is the cochlear implant recipient who offers insights into everyday musical experiences outside the test booth. Their insights can assist in revealing previously unidentified concerns and setting research and clinical priorities.

This presentation will include a) an interactive panel of cochlear implant recipients invited by the symposium's advisory committee, who will describe their experiences with music perception and performance; and b) contextualization of those experiences with prior patient-engaged research. Kate Gfeller, whose prior research has included laboratory-based studies of music perception, involvement, and training, as well as collaborative studies with CI users, will moderate the panel and offer commentary and implications for research initiatives and clinical guidelines.

Patient-engaged research, which focuses on complex real-life experiences, offers insights into those aspects of music and cochlear implants that may have been under-reported in research, as well factors that enhance or impede music enjoyment and engagement. Prior research indicates that satisfactory music experiences are dynamic in nature and influenced by multivariate factors. Thus, those CI users who have (re)established successful music engagement tend to be flexible problem solvers and have strong self-efficacy. Access to training and resources for coping is not readily available across the population of CI recipients. Motivational and logistics insights from CI users could help researchers with robust enrollment and perseverance in, as well as to provide meaningful outcomes from training programs.

Input from CI users who have achieved remarkable success in music engagement offers fresh perspectives and implications for research priorities and clinical counseling regarding dynamic real-life experiences.

*This featured presentation and panel do not 'fit' the typical presentation format. Its content and format reflect the recommendations of Jeremy Marozeau of the Symposium Advisory Committee. This presentation comprises an interactive panel discussion of CI user musicians, contextualized by Kate Gfeller, panel moderator, with published scholarship and implications for future research.*

*The panelists have been selected from individuals who have shared their testimonials.*

**Presenter Bio:** For over 30 years, Kate Gfeller, Ph.D., has directed research on music perception within the Iowa Cochlear Implant Clinical Research Team in the Department of Otolaryngology—Head and Neck Surgery, University of Iowa Hospitals and Clinics. Her research has been funded by the National Institutes of Health, the Office of Special Education and Rehabilitation, and the Department of Defense. As part of multidisciplinary teams, Gfeller has conducted basic and translational research, and provided music therapy services for children and adults with hearing losses. Her scholarship on perception and enjoyment of music has emphasized real-world complex sounds, as well as music-based programs for auditory skill development. This includes applications intended to promote more meaningful involvement in social and educational settings. Her recent studies focus on factors that CI recipients identify as impeding or enhancing participation in real-life situations involving music.

**Presenter:** Rene Gifford

**Title:** Benefits of combining electric and acoustic hearing for music sound quality and various aspects of music perception

**Affiliations:** Cochlear Implant Research Lab, Vanderbilt University Medical Center

**Abstract:** Cochlear implants (CIs) offer hearing restoration to individuals with severe-to-profound sensorineural hearing loss such that adults with postlingual onset of deafness achieve 75% correct for auditory only sentence recognition in a quiet background, on average (e.g,. Dunn et al., 2020). The acoustic cue redundancy of speech allows for high levels of speech understanding even with the relatively crude spectral representation offered by envelope-based signal coding, relatively few implanted electrodes, and considerable channel interaction associated with intracochlear electrical stimulation. A number of studies have demonstrated the benefits of combining electric and acoustic stimulation (EAS) for speech recognition in complex listening scenarios (noise, reverberation) and for music perception and appreciation. The addition of acoustic hearing to electrical stimulation is particularly important for music perception and appreciation as the spectrally and temporally complex nature of music is not well transmitted through the relatively impoverished implant signal. In this presentation, we will review the findings of our lab's studies examining the effect of acoustic hearing on music perception, appreciation, and sound quality for CI plus unilateral (bimodal) and bilateral acoustic hearing—the latter arising from CI recipients with acoustic hearing preservation. Across all studies, the combination of any acoustic hearing with electrical stimulation yielded significantly higher perceptual and qualitative performance for music tasks and there is emerging evidence that cochlear implant recipients utilizing bilateral acoustic hearing may yield significant advantages over bimodal listening alone for both sound quality judgments and stereophonic perception. We will also describe the impact acoustic bandwidth in the non-implanted ear for optimization of musical sound quality and how this might differ across listeners and tasks.

**Presenter Bio:** René Gifford, Ph.D. is a Professor in the Department of Hearing and Speech Sciences at Vanderbilt University Medical Centere. She is currently the Director of the Cochlear Implant Program at the Vanderbilt Bill Wilkerson Center in the Division of Audiology as well as the Director of the Cochlear Implant Research Laboratory. Her current research interests include speech and auditory perception via combined electric and acoustic stimulation (EAS), auditory-based language development following cochlear implantation in children, and spatial hearing abilities of individuals combining hearing aids and cochlear implants. Dr. Gifford's research has been NIH funded for nearly 20 years, she has published over 120 peer-reviewed articles, multiple book chapters, and she authored a book, now in its second edition, entitled "Cochlear Implant Patient Assessment: Evaluation of Candidacy, Performance, and Outcomes." She was the 2015 recipient of the American Speech-Language Hearing Association's Louis M. DiCarlo Award for Recent Clinical Achievement, the 2017 recipient of the Vanderbilt Chancellor's Award for Research, and the 2021 recipient of the American Academy of Audiology's Jerger Career Award for Research in Audiology.

**Presenter:** David M. Landsberger

**Title:** How music perception is influenced by the combination of acoustic and electric stimulation in single-sided deafened listeners

**Affiliations:** New York University School of Medicine

**Abstract:** The sound quality of speech and music through a cochlear implant (CI) is generally considered to be poor. Nevertheless, patients with single-sided deafness (SSD) who receive a cochlear implant are typically satisfied with their devices. Inspired by conversations with a musician who has SSD and a CI, we demonstrated that listening to music with one normal-hearing and one implanted ear was consistently preferred to listening to music with only the normal-hearing ear (Landsberger et al., 2020). This result, while consistent with the anecdotal reports from SSD musicians, was surprising to our team and other CI researchers as it was expected that adding the highly-distorted CI representation of music to the rich acoustic representation in the normal ear would highly degrade the experience. Indeed, bilaterally normal hearing listeners consistently preferred to listen to music with only one normal ear than with one normal ear and one ear listing to a vocoded CI simulation.

We have conducted subsequent studies in which SSD-CI users have been asked to conduct music-related tasks with their normal ear, their CI ear, and the two ears together. Despite the distinct preference of listening to music with the combination of a normal and CI ear, SSD users do not seem to get benefits from the addition of a CI in pitch or music related tasks. Depending on the participant and the task, performance when listening with both ears together seems to either be equivalent or poorer than that of when listening with a normal ear. In one experiment, listeners were asked to adjust the frequency of a series of sung notes to recreate the song “Happy Birthday”. Listeners who were very good at the task with their normal hearing ear alone typically did similarly well in the combined NH+CI condition. However, for listeners who were less good at the task with their NH ear alone, performance dropped noticeably in the NH+CI condition. In another experiment, we demonstrated that adding a CI to a NH ear has little effect on a listener’s perception of consonance and dissonance of simultaneous intervals (Spitzer et al., 2019). In this talk, multiple datasets showing the effects (and lack thereof) of combining a NH ear and a CI on music and pitch related tasks will be discussed

**Presenter Bio:** David Landsberger studies hearing impairment and how the auditory system responds to electrical stimulation with a cochlear implant. His work focuses on diverse topics such as improving cochlear implant algorithms, electrode designs, and music perception through a cochlear implant. He received his Ph.D. at Brown University (Providence, RI, USA) for his work in color perception. His training with cochlear implants (and the auditory system) began working as a postdoctoral researcher with Colette McKay, first at the University of Melbourne in Australia and then at Aston University in Birmingham, England. Subsequently, he moved to Los Angeles to work with Bob Shannon at the House Ear Institute. In 2013, he joined the Department of Otolaryngology at the New York University School of Medicine. He is a co-founder of York Sound Inc, which developed a noise reduction algorithm for hearing aids and cochlear implants. He sits on the board of the Hearing Loss Association of America – NYC chapter.

**Presenter:** Charles Limb

**Title:** Tuning cochlear implants using CT-based pitch mapping

**Affiliations:** Douglas Grant Cochlear Implant Center, University of California San Francisco School of Medicine, San Francisco, CA

**Abstract:** High-resolution CT imaging techniques allow improved visualization of cochlear implant electrode location within the cochlea. The goal of this study is to utilize individual electrode localization data to improve pitch mapping of cochlear implants, with the hypothesis that personalized image-guided mapping should lead to better performance on pitch tasks than default clinical mapping as result of overall improvements in cochlear implant tuning. We discuss the derivation of electrode center channel frequencies from imaging data as well as the development of pitch assessments to examine the impact of individualized mapping changes on pitch tuning. We will also present preliminary data on CI user performance on pitch based tasks after image-guided mapping.

**Presenter Bio:** Dr. Charles Limb is the Francis A. Sooy Professor of Otolaryngology-Head and Neck Surgery and the Chief of the Division of Otology, Neurotology and Skull Base Surgery at UC San Francisco. He is also the Director of the Douglas Grant Cochlear Implant Center at UCSF and holds a joint appointment in the Department of Neurosurgery. Dr. Limb is the current President of the American Auditory Society and is also the Co-Director for the Sound Health Network sponsored by the National Endowment for the Arts in collaboration with the NIH. He is also the PI of a National Endowment for the Arts Research Lab that studies the neural basis of musical creativity. His work on creativity and music perception in cochlear implant users has been featured in media and venues worldwide including National Public Radio, TED, 60 Minutes, National Geographic, the New York Times, PBS, CNN, Scientific American, the British Broadcasting Company, the Kennedy Center, Smithsonian Institute, the Library of Congress, the Sundance Film Festival, Canadian Broadcasting Company, Wired, Baltimore Symphony Orchestra and the American Museum of Natural History.

**Presenter:** Jeremy Marozeau[1], Charlotte Nordin[2], and Raphaël Ortis[2]

**Title:** An audio-tactile artistic installation to enhance musical experiences

**Affiliations:** Music and Cochlear Implant Lab[1], Technical University of Denmark Independent Artists[2]

**Abstract:** Everybody needs art in their life! Unfortunately, physical and mental handicaps often will create a wall between a person and an artistic creation. This presentation will describe the ongoing journey of our collaboration that merges science and art to help people with severe hearing impairment to fully experience a musical creation. The project was initiated to merge a scientific approach to create an audio-tactile device for CI users and an artistic approach toward a multi-sensory musical experience. Through a series of initial meetings, the first generation of audio-tactile installations was developed in collaboration with the Museum of Art and History of Geneva (MAH). A first temporary exhibition within the "inclusion week" of the MAH took place in October 2020. Five podiums were equipped with powerful tactors (vibrating transducers). For 20 minutes, the audience could sit down on the podium and listen to different artists' live concerts. Part of the musical signal was sent through two loudspeakers and part directly through the tactors. Even though this first implementation of the project was simple, the audience's response was highly positive. The museum was also very enthusiastic and expressed its desire to host an updated version within their permanent collection. We are working now to create a much more ambitious version of the installation.

This presentation will first cover the technical and scientific aspects of the first and future generation of the installation. Then, we will cover the musical aspect and artistic approach of the first exhibition. Finally, we will discuss the audience's reaction and how it has influenced the next step of the project.

**Presenter Bio:** Jeremy Marozeau is an Associate Professor at the Technical University of Denmark. He is leading the "Cochlear Implant and Music" team within the department of Health technology. He received a BEng degree in 1999 in Microtechnology Engineering from Swiss Institute of Technology (EPFL), an MSc degree in 2000 in Acoustics and Signal Processing Applied to Music, and a PhD in 2004 from the Institute for Research and Coordination Acoustic Music (IRCAM) and the University of Paris VI. After working at the French National Center for Scientific Research (CNRS, Marseille) on modeling the loudness of impulsive sounds, he continued his research on loudness as a Research Associate at Northeastern University, Boston, in 2005. Three years later, he worked as a senior researcher at the Bionics Institute in Melbourne, with the aim of improving music perception for cochlear implants users. In 2014, he joined the Hearing Systems Group at DTU as an Associate Professor.

**Presenter:** Collette McKay

**Title:** Does music training have a role in cochlear implant (re)habilitation?

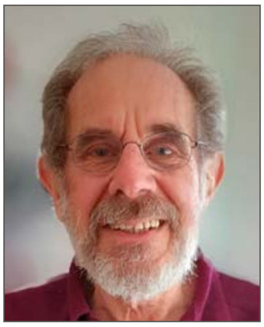
**Affiliations:** The University of Melbourne & The Bionics Institute, Melbourne, Australia

**Abstract:** Music participation is an important part of being human for the vast majority of people, whether they are regular listeners, music performers, or just casually singing or dancing along to music. For people with a hearing impairment, music participation is just as important as it is for people with normal hearing, even if their impairment may distort the quality of their listening to varying degrees. So, yes, it is important that people with cochlear implants have access to all the ways of participating in music that people with normal hearing have. But does music training (e.g. learning to play a musical instrument or singing lessons) have benefits other than playing or singing better, and other the social opportunities that participation in music making might bring? Many studies have tested hypotheses that music training improves cognitive skills and speech perception. However, the majority of the studies have a poor research design that does not allow inferences to be made about the hypothesis. Systematic reviews that take into account research design quality have found that there is no evidence for such benefits and that the common belief in the field of those benefits is due to misinterpretation of empirical data and/or confirmation bias. In this presentation, I will discuss the common flaws in research design in music training studies, and introduce other studies that throw a different light on the interpretation of the "musicianship" effect, in which musicians are often found to have superior cognitive or speech perception skills than non-musicians. These latter studies show that musicians may be different from musicians, but because of their innate abilities, and not because they undertook music training. In summary; yes, music is an important part of CI (re)habilitation, but not as a tool to make people smarter or to hear speech better.

The Bionics Institute acknowledges the support it receives from the Victorian Government through its Operational Infrastructure Support Program.

**Presenter Bio:** Professor McKay is an international leader in in hearing research and is currently the Principal Scientist at the Bionics Institute in Melbourne. Her multidisciplinary research aims to improve the lives of people with hearing impairment. She has contributed significantly to the design and signal processing strategies used in the family of cochlear implants manufactured by Cochlear Ltd. She graduated and received her PhD from the University of Melbourne in the fields of mathematics and physics. From 1991-2004, she was Research Fellow, Senior Research Fellow, and then Principal Research Fellow at the University of Melbourne Department of Otolaryngology. From 2005 to 2013 she held chair and research group leadership positions at Aston University, Birmingham, and Manchester University in the UK. Since 2013 she has led the Translational Hearing Research group at the Bionics Institute, and has established Australia's first brain imaging laboratory for hearing research using functional near-infrared spectroscopy.

**Presenter:** Brian J. Moore



**Title:** Listening to music through hearing aids: Potential lessons for cochlear implants

**Affiliations:** University of Cambridge

**Abstract:** Users of hearing aids (HAs) experience several problems when listening to music, some of which are relevant to cochlear implants (CIs). One problem is related to the very high peak levels that occur in live music, which can reach 120 dB SPL. Some HAs (and CIs) overload at such levels, because of the limited dynamic range of the microphones and analogue-to-digital converters (ADCs), leading to perceived distortion. Potential solutions are to use 24-bit ADCs or to include an adjustable gain between the microphones and the ADCs. A related problem is how to squeeze the wide dynamic range of music into the limited dynamic range of the user, which can be only 10-20 dB for CI users. In HAs, this is usually done via multi-channel amplitude compression (also called automatic gain control, AGC), which can be fast acting or slow acting or use dual time constants. In most CIs, a single-channel front-end AGC is applied to the broadband input signal. This is followed by filtering into frequency channels, derivation of the envelope of the signal in each channel, use of the envelope to modulate a train of biphasic pulses, and application of instantaneous amplitude compression to the pulse trains delivered to each electrode. The use of single-channel front-end AGC introduces several problems: (1) a relatively intense narrowband signal (e.g. a strong bass sound) will reduce the level for ALL frequency components, making some parts of the music harder to hear; (2) if the AGC is fast acting, it introduces cross-modulation effects, such that a brief strong signal from one source (e.g. a drum) leads to a reduction in gain for another sound source (e.g. strings). The cross-modulation effect can make a steady sound (e.g. sustained strings or a sung note) appear to fluctuate in level, and it may also make it harder to segregate sound sources. Potential solutions are to use several frequency channels in the front-end AGC and to use slow-acting (or dual time-contant) AGC rather than fast-acting AGC. An alternative is to dispense with the front-end AGC and to apply all amplitude compression to the pulse trains delivered to each electrode, as is done in the Oticon Medical system. However, this system has been designed to work well with speech signals, and, to my knowledge, it has not been evaluated for music listening.

**Presenter Bio:** Brian Moore is Emeritus Professor of Auditory Perception in the University of Cambridge. His research focuses on the perception of sound by people with normal and impaired hearing, and on the design and fitting of hearing aids. He is a Fellow of the Royal Society, the Academy of Medical Sciences, the Acoustical Society of America, the British Society of Audiology, and the Audio Engineering Society. He has received major awards from the Acoustical Society of America, the American Academy of Audiology, the Association for Research in Otolaryngology, and the American Auditory Society. He has an Honorary Doctorate from Adam Mickiewicz University, Poland. He has published over 620 refereed journal articles.

**Presenter:** Waldo Nogueira

**Title:** Signal processing and sound coding strategies to make music more accessible for cochlear implant users

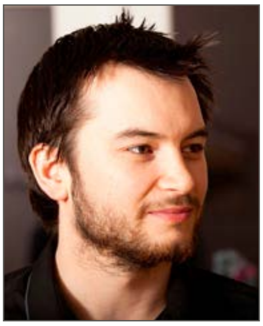
**Affiliations:** Hannover Medical School

**Abstract:** Music plays an essential role in people's lives and is part of many socio-cultural and educational events. Music is the most complex acoustic signal as it uses the full dynamic, bandwidth, and resolution of the human auditory system. Cochlear implants can restore hearing for the hearing impaired but have been solely designed to restore speech intelligibility rather than music. Moreover, CIs lead to a severely distorted perception of music because key musical features like pitch and timbre are poorly transmitted. For this reason, it is necessary to adapt existing and create new technologies to improve the music experience of CI users.

This presentation, will review recent advances to make music more enjoyable for CI users, including customized music compositions, music pre-processing methods to enhance the singing voice or certain music objects, as well as CI sound coding strategies. Based on previous research that showed that CI users, in general, prefer the singing voice to be enhanced with respect to the background instruments (Buyens et al. 2014; Pons et al. 2016; Gajecki and Nogueira, 2018), this presentation will introduce a methodology to optimize the parameters of a sound coding strategy for that purpose. Moreover, this presentation will review some methods designed to evaluate music perception through sound coding strategies that emphasize some component of music based on objective instrumental measures, behavioral responses and electrophysiological recordings.

**Presenter Bio:** Waldo Nogueira received his engineering degree in Electrical Engineering from the Technical University of Catalonia in 2003 and his Dr.-Ing. degree from the Leibniz University of Hanover at Laboratory of Information Technology. In 2008 he joined the European R&D center of Advanced Bionics in Europe. In 2011 he became Post-Doc (visiting professor) at the Pompeu Fabra University in Barcelona, where he started a research line in the area of music accessibility for hearing impaired at the Music Technology Group. During that time he worked as a consultant for companies such as Advanced Bionics and Jacoti developing real time audio signal processing for mobile devices. Since 2013 he leads the auditory prosthetic group (APG) as an assistant professor (W1-professorship) and since 2010 as an associate professor (W2-professorship) of the Medical University Hannover (MHH) and the cluster of excellence Hearing4all. His teaching experience covers courses on data transmission, spatial audio, speech processing, neural signal processing and audiology. His research interests are audio and neural signal processing, computational models of the auditory system and psychoacoustics in the field of auditory implants.

**Presenter:** Lorenzo Picinali[1] and Yuli Levtov[2]



**Title:** Improving music listening for bilateral cochlear implant users using immersive audio and VR-based applications

**Affiliations:** Imperial College London[1]
Reactify Music[2]

**Abstract:** Similarly to what happens in many other fields related with technology and perception, in order to improve music listening for cochlear implant users two approaches can be employed. The first one aims at adapting/optimising the devices to the task (i.e. music listening) and to the specific user, for example by designing novel algorithms and improving the fitting. The second one looks at the problem from a different point of view, aiming at adapting the listener to the task and device, which is often achieved through perceptual and procedural training. This presentation will initially focus on the work we started within the 3D Tune-In project and the development of the Musiclarity application (www.musiclarity.com), looking specifically at personalisation, interaction and spatial audio when dealing with music listening issues for hearing aid users. We will then introduce the BEARS project, which focusses specifically on teenage cochlear implant users, and the approach we are currently adopting for improving not only the audio playback, signal processing, user interface and interaction, but also the ability of the listeners to use the available cues and tools, and enhance their music listening skills through training using immersive and VR-based applications.

**Presenter Bio:** Lorenzo Picinali -I am a Reader in Audio Experience Design at Imperial College London. In the past years I have worked in Italy, France and UK on projects related with binaural spatialisation and spatial hearing, looking both at the theoretical side of things, and at applications in areas such as hearing aids technologies, auditory displays, audio and haptic interaction, auditory training and, more in general, acoustic virtual and augmented reality.

Yuli Levtov – I am a Reactive Music Producer, co-founder and director of Reactify. I am a music programmer specializing in next-generation formats of music, such as interactive, reactive and generative music.

**Presenter:** Deborah Vickers

**Title:** Maximising engagement and effectiveness of training

**Affiliations:** Cambridge Hearing Group, SOUND Lab, University of Cambridge

**Abstract:** Auditory training interventions frequently show benefit for on-task outcomes that were directly trained but generalisation to non-trained skills and long-term retention of training effects are less common and are often seldom measured.

Current thinking is that a combination of analytic and synthetic tasks and multi-modal delivery is the most effective approach for transferring learnt skills to other modalities. The likelihood for improvements can also depend on listener characteristics such as hearing status (normal hearing, hearing aid or cochlear implant listeners), language levels, family support and motivation.

This research looked at maximising the impact of weekly in-person classroom-based singing lessons with primary school children, aged 5 to 7 years, using hearing devices. The lessons focussed on exploring melody (perception and production) in a group context. Visual imagery was used to reinforce the activities in the group lessons and the materials involved repetition of simple words aimed at enhancing vocabulary. A formalised programme of lesson plans was created, and the lessons were delivered by an early years music specialist.

There were two phases.

In the first phase (proof of concept) a group of 12 hearing device users (6 bilateral cochlear implants, 3 bimodal and 3 bilateral hearing aid) and a group of 18 normal hearing listeners attended the singing lessons for a 20-week period. Assessments included singing abilities, including pitch range and singing accuracy, simulated piano chord pitch discrimination and speech in noise perception. Measures were presented at baseline, 10 and 20 week stages.

Both groups demonstrated a significant improvement in singing range, singing accuracy scores and pitch discrimination over time. The normal hearing group scored significantly higher on all measures than hearing device users but there was no interaction with timepoint. The results did not show any significant changes over time for the speech-in-noise task for either group but for normal hearing children they were at the expected level. Hearing device users performed more poorly but the analysis was under powered to separate hearing aid and cochlear implant users.

In the second phase (exploration of training parameters) the goal was to compare different hearing device users (N=39) and explore different timescales of training. The main purpose was to determine if a greater number of training sessions would lead to improvements for speech-in-noise scores. The findings showed that by 40 weeks that there was an overall improvement in speech-in-noise perception and that the hearing aid users demonstrated benefit by 20 weeks but that the cochlear implant users required the full 40 weeks to show improvements.

Maximising the impact of training is complex and should be personalised for greatest effect. Investigations are time consuming and practicalities often limit the assessment of generalisation and retention. We were able to assess generalisation but long-term retention of skills was not possible due to the pandemic.

**Presenter Bio:** Deborah Vickers is a Principal Research Associate at the University of Cambridge, leading the SOUND (Sensory Optimisation Using Neuroscience for Devices) Lab in the Clinical Neurosciences Department. Her research team are funded by a Medical Research Council Senior Fellowship that explores electrophysiological measurement of sound processing in cochlear implant users, and a Programme grant from the National Institute Hearing Research to explore virtual reality training for older children and teenagers with bilateral cochlear implants. This latter project incorporates spatial music training as part of a multi-modal training programme. Earlier in her research career she worked as a research associate in Brian Moore's lab, University of Cambridge and at University College London where she conducted her PhD studies and in a later period as an Associate Professor in Speech and Hearing Research.

**Presenter:** Peter Vuust

**Title:** The musical mind that predicts

**Affiliations:** Music in the Brain, Århus University

**Abstract:** Music is ubiquitous across human cultures—as a source of affective and pleasurable experience, moving us both physically and emotionally—and learning to play music shapes both brain structure and function. Music processing in the brain—namely, perception of melody, harmony, and rhythm—has traditionally been studied as an auditory phenomenon using passive listening paradigms. However, when listening to music, we actively generate predictions about what is likely to happen next. This enactive aspect has led to a more complete understanding of music processing involving brain structures implicated in action, emotion, and learning.

The present talk highlights how music perception, action, emotion, and learning all rest on the human brain's fundamental capacity for prediction—as formulated by the predictive coding of music model and elucidates how this formulation of music perception and expertise in individuals can be extended to account for the dynamics and underlying brain mechanisms of collective music making. This sheds new light on what makes music meaningful from a neuroscientific perspective.

**Presenter Bio:** Peter Vuust is a unique combination of a renowned scientist and a world class musician. As a researcher, he is Denmark's leading expert in the field of music and the brain – a research field he has single-handedly built up as leader of the group Music In the Brain. He is internationally recognised, widely quoted and received in October 2014 DKK 52 million and in August 2020 DKK 46 million from the Danish National Research Foundation's centre to found the Center for Music In the Brain.

**Presenter:** Scott C. Aker[1,3]

**Title:** Effect of audio-tactile congruence in vibrotactile music enhancement for cochlear implant users

**Co-authors:** Kathleen F. Faulkner[1], Hamish Innes-Brown[2], Marianna Vatti[1] and Jeremy Marozeau[3]

**Affiliations:** Oticon Medical[1], Eriksholm Research Center[2], Music and Cochlear Implants Lab[3], Department of Health Technology, Technical University of Denmark; Oticon Medical

**Abstract:** Background: Vibrotactile stimulation has been shown to enhance music quality for listeners and may therefore provide a novel way to enhance music for cochlear implant (CI) users. However, as CI users do not perceive musical dimensions in the same way as non-CI users, it is important to understand how congruence between the vibrotactile stimulation and music affects this enhancement to see if such a solution would be viable for CI users. An experiment was designed to break down vibrotactile music enhancement into a series of perceptual congruences between the vibrotactile stimulation and the music and performed with both CI users and non-CI users. The results could provide data for the design of a vibrotactile device for CI users in the future.

Method: Twenty test subjects without CIs and fifteen with CIs participated in the experiment. Music stimuli was presented over supra-aural headphones for subjects without CIs and streamed directly to the CI for subjects with CIs. Vibrotactile stimuli were presented through a single, vibrotactile actuator held between the thumb and forefinger and were designed so the perceptual dimensions of the vibration: frequency, intensity, and timing, were congruent with the perceptual dimensions of the music: pitch, intensity, and rhythm. Incongruent versions of the stimuli pairs were created by altering the perceptual dimensions of the vibrotactile stimuli independently of the audio stimuli. Test subjects were asked to rate their preference of congruent against incongruent versions in a MUSHRA-like set-up. Results: On average, test subjects without CIs rated stimuli pairs lower when the intensity of the vibrotactile stimuli and the intensity of the music was incongruent compared to when the intensities of the stimuli were congruent, and when the two stimuli were misaligned in time compared to being aligned.

Test subjects with CIs could be separated into two groups: the first group, 6 out of 15 subjects, consistently rated stimuli misaligned in time lower than stimuli aligned in time while the second group did not. Only the first group also rated stimuli with incongruent intensities lower than stimuli with congruent intensities, like test subjects with CIs.

**Discussions/Conclusions:** Results suggest that for subjects without CIs, time alignment and intensity congruence between music and vibrotactile stimuli are the most important components of vibrotactile music enhancement. For certain subjects with CIs, time alignment and intensity congruence between music and vibrotactile stimulation are similarly important as shown in subjects without CIs. However, most subjects with CIs showed no congruence condition favored over the others. The results suggest while some CI users benefit from the same perceptual congruences between vibrotactile stimulation and music as non-CI users, other CI users could require a different strategy for vibrotactile music enhancement than congruence between the two modalities.

**Presenter Bio:** Scott C. Aker is an Industrial PhD student at Oticon Medical and the Music and CI Lab at the Hearing Systems Group of the Technical University of Denmark. His project involves investigating using tactile stimulation to improve the music experience of people with cochlear implants. He has previously completed his Bachelors of Engineering Science in Electrical Engineering and a Masters of Engineering Science in Digital Signal Processing at Western University, Canada, where his thesis project focused on speech quality evaluations of hearing aid beamformers. During his masters he has also completed a short internship at AudioScan as a DSP software engineering student.

**Presenter:** Manuel Segovia Martinez

**Title:** Development of next generation cochlear implant coding strategies

**Affiliations:** Oticon Medical

**Abstract:** Cochlear Implants have been extremely successful in improving the quality-of-life of their users. CI users are achieving a speech understanding in quiet which is close to normal hearing values. Nevertheless, CI users still struggle in complex environments such as speech in noise and music performance.

Oticon Medical has invested heavily on advanced sound processing strategies designed to assist the user in adverse conditions.

During this talk I would like to present some of the main high-level concepts around the development of our next generation CI processing strategy, the Crystalis+. The core processing is based on the Synthetic Feature eXtraction (SFX) algorithm presented at Music & CI symposium 2018.

Crystalis+ provides two main advantages: improved signal feature extraction and flexible frequency allocation.

The improved signal feature extraction significantly reduces the input smearing compared to the current state of the art (input smearing is mainly due to the analysis of the input signal). Combined with a stimulation mode assumed to favour more focused excitation [Stahl et al., submitted] the overall CI strategy aims at better conveying spectral resolution, which has been moderately but significantly correlated with word recognition [Berenstein et al. 2008]. The relation of better spectral resolution and music performance will be explored on our clinical protocol.

Finer control of the frequency allocation mapping removes the constraints of standard FFT strategies. This is an enabler for frequency allocations which either improve music performance [Tabibi et al. 2017] or that get us closer to the spiral ganglion frequency map.

To conclude this talk I will present the main hypothesis of our clinical protocol. This protocol will be executed under the supervision of Prof. Enrique Lopez Poveda at the University of Salamanca.

**Presenter Bio:** Manuel Segovia-Martinez is Senior Translational Research Manager at Oticon Medical focused on the areas of Audiology and Signal Processing. He joined Oticon Medical in 2012 as senior signal processing engineer and embedded solutions manager, and has designed several coding strategies for cochlear implants as XDP, Voice Guard and Coordinated Adaptive Processing. He has also been responsible for the embedded software for several generations of Oticon Medical Sound Processors.

Manuel's current research interests include CI strategies for improving music perception, binaural hearing, and auditory mathematical models. He coordinates collaborations on research grants in some of these areas with a number of research centres including Hannover Medical School and the University of Salamanca.

Manuel holds a PhD on Medical Image Processing from the University of Surrey, where he developed 3D imaging algorithms for dementia diagnosis.

**Presenter:** Marianna Vatti

**Title:** Effect of frequency-to-electrode allocation manipulations on music features predicted with objective measures

**Co-authors:** Yue Zhang, Pierre Stahl and Manuel Segovia Martinez

**Affiliations:** Oticon Medical

**Abstract:** Most cochlear implant (CI) users have limited pitch resolution. One of the reasons is the degraded temporal and frequency resolution provided by the sound coding strategy of the CI. The Synthetic Feature eXtraction (SFX) is a new sound processing strategy designed to provide increased spectral and temporal resolution compared to the standard FFT. The increased resolution provided by SFX allows for a more detailed manipulation of the bandpass filter parameters, i.e., the filter slope, the filter bandwidth and the filter distribution. These parameters control for the selectivity and precision of frequency-to-electrode mapping. Narrower filter spacing, particularly at low frequencies, has been shown to improve performance in both music and speech related tasks. This modified assignment of the cutoff frequencies leads to more resolution in the lower frequency channels compared to the standard FFT strategy.

In this study we investigate how SFX may allow the definition of parameters settings that could achieve to an optimal CI hearing. We present different frequency-to-electrode allocations that could improve music and speech outcomes and investigate how the modified assignment of the cutoff frequencies affect the musical features of the input sounds. We compare the SFX with the standard FFT signal processing as well as other filterbank approaches. The reconstructed signals are analysed with the Music Information Retrieval toolbox (MIR), designed to detect features from musical signals. The results of each MIR analysis are passed through a dimension reduction method to extract the principal robust components that constitute the sounds. A parametric statistical model is then used to estimate the level of distortion introduced by the different assignments of cut-off frequencies on the most prominent musical features. The results will potentially provide guidance to improve the frequency-to-electrode allocation fittings in CI.

**Presenter Bio:** Marianna Vatti is a Senior Research Engineer at Oticon Medical in Denmark. She holds an MEng in electronics and a MSc in Acoustics Engineering. She has spent six years at Eriksholm Research Centre working with the early design of algorithms and psychoacoustic tests aimed to improve speech and pitch perception in hearing impaired listeners. Since 2017, she has been working at Oticon Medical within the areas of audiology and signal processing with particular interest in music perception and gaming in music rehabilitation.

**Title:** Musi-CI training: hearing training from a musical perspective by and for cochlear implant users and how to fit this into regular cochlear implant rehabilitation

**Authors:** **Cilia Beijk[1,2], Joke Veltman[3], Adinda Groenhuis[4], Alex Hoetink[4,5], Huib Versnel[4,5], Wendy Huinck[1,2], Marjo Maas[6,7]**

**Affiliations:** Department of Otorhinolaryngology and Head and Neck Surgery, Radboud university medical center Nijmegen, the Netherlands[1]. Donders Institute for Brain, Cognition and Behavior, Radboud university Nijmegen, the Netherlands[2]. Foundation Musi-CI, Breda, the Netherlands[3]. Department of Otorhinolaryngology and Head & Neck Surgery, University Medical Center Utrecht, Utrecht, the Netherlands[4]. UMC Utrecht Brain Center, Utrecht, the Netherlands[5]. Department IQ Healthcare, Radboud university medical center, Nijmegen, the Netherlands[6]. HAN University of Applied Sciences, Nijmegen, the Netherlands[7].

**Background:** Joke Veltman, pianist and cochlear implant (CI) user, developed an extensive musical hearing training, together with the CI-teams of Radboudumc Nijmegen and UMC Utrecht. This Musi-CI training fits the needs and wishes of many CI-users to find their way back to music enjoyment. It focusses on their self-efficacy and self-motivation. Training of auditory attention and working memory plays an important role. We have been exploring the experiences and the impact on music enjoyment of CI-users, and how to integrate parts of this training in our current practice of hearing therapy for CI-users.

**Methods:** From September 2019 until December 2020 the Musi-CI training has been developed by adjusting and evaluating, together with 37 CI-users (ten groups of 3 – 5 participants), the cooperating CI-teams, and researchers. The Musi-CI training is an intensive training (8 lessons within 3 months) that exposes participants from simple everyday music into increasingly more complicated music. Exercises are included, based on the Ronnie Gardiner Method (RGM) and Neurologic Music Therapy. To realize an online opportunity to train discrimination of pitch and small melodies, a first version of a Melody Game is developed.

We explored the experiences of participants with questionnaires, focus groups and interviews. Data were audio-recorded, transcribed verbatim and thematically analysed.
For the rehabilitation part of the research 13 CI-participants (35% of participants of the training) and 6 professionals (therapists of the CI-team Radboudumc) have been interviewed by bachelor students speech therapy. Semi-structured interviewing and structured open questionnaires have been used.

**Results:** All training sessions have been attended very well. Over 50% of the participants reported aversion to music before training. The majority of the participants were surprised about their positive training results: they shifted to tolerating or even enjoying musical sounds.
Experience has shown that CI-users with about one year of CI-use profit the best of the Musi-CI training. The Musi-CI Melody Game proved to be an effective instrument to train pitch and melodic contour discrimination. Further development is required.

For the rehabilitation part the results show that both CI users and professionals expressed a need for music training during the first year of CI rehabilitation. Introduction of music in the therapy should not start until at least 3 months after the start of the therapy, and that speech perception still is the most important issue for training during this first year. However, there was a different view of the content of the therapy; ‘training melody’ was found important by 11/13 (84%) of the CI users versus 3/6 (50%) of the professionals, practicing ‘rhythm and beat’ was found important by 6/13 (46%) of the CI users and 3/6 (50%) of the professionals, and ‘recognizing musical instruments’ was found important by 8/13 (62%) of the CI users versus all of the 6 (100%) professionals.

**Discussions:** The Musi-CI project is a dynamic process. A next step will be to investigate how exercises of the Musi-CI training can be integrated into current CI-rehabilitation. The main purpose is to help CI-users not to develop an aversion to music by bringing them into contact with non-complex music as early as possible. CI-users and therapists show a few different preferences on the musical exercises.

**Acknowledgements:** ZonMw – ‘Voor Elkaar!’ HAN Students Bachelor programme Speech Therapy.

**Title:** Can we improve music perception and appreciation using strategic apical electrode deactivation?

**Authors:** Katelyn Berg and René Gifford

**Affiliations:** Vanderbilt University, USA

Channel interaction is the overlap in electric fields from adjacent electrode contacts. In cochlear implant (CI) stimulation, channel interaction is unavoidable because the electrode contacts rest in a highly conductive fluid and are relatively far from the neural interface, contributing to poor spectral resolution (Jones et al., 2013; Won et al., 2014). Speech understanding appears most affected by apical region channel interaction, likely due to its responsibility for conveying first formant information, the suboptimal orientation of distal spiral ganglion as a result of a shorter cochlear duct, and the potential for cross-turn stimulation resulting from poor placement of the electrode array outside scala tympani (Henry et al., 2000; Goehring et al., 2021).

Recent evidence suggests that electrode arrays placed closer to the modiolus or those with large spacing between adjacent electrodes may achieve greater channel independence (Berg et al., 2019a; Berg et al., 2019b). One proposed method of increasing channel independence is by deactivating electrodes identified as causing overlapping stimulation patterns (e.g., Noble et al., 2014; Bierer and Litvak, 2016). This study aimed to 1) determine the impact of apical electrode deactivation on spectral-dependent tasks and 2) determine the impact of electrode placement on the degree of benefit from apical electrode deactivation.

An A-B-A-B study design was used, comparing the participant's clinical map (A) and their clinical map with electrode two (Advanced Bionics and MED-EL devices) or electrode 21 (Cochlear devices) deactivated (B). The UW-CAMP pitch discrimination subtest, the BKB-SIN test, and a test of musical SQ and enjoyment subjective ratings using a randomized set of 10-second musical clips were assessed for each condition. Electrode placement was determined by CT imaging using validated CI position analysis algorithms (e.g., Noble et al., 2014). Participants included 8 (expected N = 30) adult CI recipients (mean age: 70 years, range: 58-77 years; 4 females). All participants had at least six months of CI experience.

Preliminary results showed pitch discrimination thresholds improved with deactivation of electrode 2 for all frequencies tested at the group level, including 262 Hz (mean benefit: 0.6 semitones, range: -0.4-1.8 semitones); 330 Hz (mean benefit: 0.7 semitones, range: -1.6-3.1 semitones); and 392 Hz (mean benefit: 0.1 semitones, range: -0.9-1.4 semitones). BKB-SIN scores improved at the group level (mean SNR benefit: 1.7 dB, range: -0.8-3.3 dB). Subjective musical SQ ratings (1-10; 1 = very poor SQ; 10 = very good SQ) improved at the group level (mean benefit: 0.3, range: -0.8-1.3). Subjective musical enjoyment ratings (1-10; 1 = low enjoyment SQ; 10 = high enjoyment) improved at the group level (mean benefit: 0.3, range: -0.2-1.2).

These preliminary findings suggest that strategic apical electrode deactivation may improve pitch discrimination, speech recognition in noise, and musical SQ and enjoyment ratings. Once data collection is complete, the impact of electrode placement (electrode-to-modiolus distance, angle of insertion depth, and scalar location), CI manufacturer, musical experience, and processor wear time on study results will be investigated.

**Title:** Can spectral complexity reduction improve music perception in cochlear implant users?

**Authors:** Johannes Gauer, Anil Nagathil, Benjamin Lentz and Rainer Martin

**Affiliations:** Ruhr-Universität Bochum, Institute of Communication Acoustics, Germany

While cochlear implant (CI) users often achieve a good restoration of speech perception their access to music is still highly limited. The coarse spectral representation provided by the CI particularly impairs pitch and timbre perception. Temporal cues, however, are perceived comparably to normal-hearing (NH) listeners. We hypothesize that both dense spectral structures and the lack of pronounced temporal variations reduce the preference for a given music piece and increase its perceived complexity. Hence, we provide here an overview on music preprocessing schemes based on reduced-rank approximations we have proposed to improve music enjoyment in CI listeners.

Some music preprocessing methods comprise an algorithmic separation and subsequent remix of different voices whereas their spectral structure is not altered. Reduced-rank approximations of music signals in the frequency-domain, however, emphasize the main melody and the dominant spectral components. Simultaneously they attenuate less prominent partials across the signal spectrum and thus reduce the spectral complexity of both the leading voice and the accompaniment. Therefore, we have proposed a blind identification of the dominant spectral components employing either principal component analysis (PCA) or subspace tracking (SCPAST) which facilitates low-latency processing. To improve the overall performance on beat-based music genres the PCA method has also been combined with a preceding harmonic/percussive source separation (HPCA+P). Besides instrumental assessments, all these approaches were evaluated in listening experiments.

Both PCA and SCPAST methods attenuate the accompaniment up to 8 dB for a small number of retained spectral components. In paired comparison tests with classical chamber music excerpts and 14 CI listeners, significant preference rates of 73.7% were obtained for the PCA-based method. In another experiment ten CI listeners chose mostly small numbers from a given range of components producing strong complexity reduction. Here, also computational measures indicate music complexity simplifications. For the SCPAST method, eight CI listeners indicated a median preference of up to 75% for those signals processed with the highest amount of complexity reduction included in the experiment. For pop music with CI simulation, the HPCA+P combination was significantly preferred over the unprocessed reference by 17 NH listeners with CI simulation. Additional performance improvements could be shown for a binaural processing scheme.

All the above results corroborate our hypothesis that preserving rhythmic information and reducing the spectral complexity will facilitate access to music in CI listeners. Thus, as long as the current clinical implant designs and coding strategies form a bottleneck for richer spectral transmissions, we consider spectral complexity reduction approaches as promising means to improve the music perception of CI users.

This work is funded by the German Research Foundation (DFG), Collaborative Research Center 823, Subproject B3.

**Title:** Factors influencing music engagement in everyday lives of pediatric cochlear implant users

**Authors:** **Kate Gfeller and Ruth Mallalieu**

**Affiliations:** The University of Iowa, USA

**Background:** Cochlear implants (CIs), which are highly effective in supporting speech perception in quiet listening conditions, are significantly poorer in conveying musical sounds. Prior research indicates a dynamic multivariate process that facilitates or impedes music experiences for adult CI users. While pediatric recipients use similar technology, early-onset hearing loss affects auditory development and consequently, music perception and conceptualization of musical structures. Furthermore, children's daily lives are structured differently from adults; many life experiences revolve around educational requirements, and research indicates that familial values have a significant impact on music involvement of pediatric CI users. Many questions remain, particularly regarding experiences in everyday life (outside of the clinic) from the perspective of pediatric CI users and the adults who influence those perspectives (e.g., parents, educators, and healthcare professionals).

**Methods:** The first aim of this study is to understand more fully pediatric CI users' perspectives of musical experiences in everyday life: music listening, and music engagement via participation in instruction and ensembles. These findings underpin the second aim, the development of a model of everyday music experiences that could inform future (re)habilitative practices and research initiatives.

This is a study in progress. Qualitative and patient-engaged research methodologies were chosen to focus expressly on the perspectives of CI users outside of formal test situations. Open-ended interview questions emphasizing perspectives most relevant to pediatric CI users were developed through preparatory interviews of stakeholders: pediatric CI users (adolescent or young adults), parents, hearing professionals, and educators. The first stage of interviews involves pre and postlingually deaf pediatric CI recipients (~7-10 per category to achieve saturation) engaged in music. Interviews are conducted online to encourage broad participation and inclusion. The questions focus on purposeful music listening and participation in music making in educational, familial, and social contexts. Results: Consistent with qualitative methodology, the interviews are analyzed using an integrative approach of inductive and deductive coding methods. The initial coding categories are informed by the Reciprocal Feedback Model of Music Response (Hargreaves, Miell, and MacDonald, 2005), which conceptualizes musical responses as dynamic interactions of the listener, the situation, and characteristics of the music. This presentation focuses on the first stage of data collection, interviews of pediatric CI users. Subsequent stages of research will involve interviews with other stakeholders: parents, instructors, and hearing professionals. Those data will be coded and examined in relation to the responses of the pediatric CI users. The codes and themes that emerge will be organized into a model that reveals the relationships among the components.

**Discussion/Conclusions:** These findings can complement controlled laboratory studies and deepen understanding of factors that enhance or undermine complex and dynamic music experiences in everyday life.

**Title:** Rhythmic training: an effective tool for children with cochlear implants

**Authors:** **Céline Hidalgo and Daniele Schon**

**Affiliations:** Aix Marseille University; Institut de Neurosciences des Systèmes, France

Despite good speech and language outcomes for many profound deaf children fitted with cochlear implants, some of them do not reach normal hearing children's language levels and academic achievement. The source of this variability is not fully explained but one part of it could be due to deficits in high cognitive processes. Research in neurosciences has shown that predictions, and more precisely temporal predictions, are important to make sense of the surrounding world and to communicate. This is particularly true in noisy environment and and interactive contexts such as conversation. Research has also shown that music practice, through its rhythmic feature, fosters temporal predictions by enhancing phase synchronization between the auditory cortex and the speech signal but also between different areas involved in speech processing.

In a first experiment we analysed children with cochlear implants rhythmic skills and their links with their speech perception capacities. We found that children with cochlear implants have deficits in synchronization sensori motor skills compared to normal-hearing children, but this effect is higher for complex rhythmic structures. This ability was the best predictor of their speech perception as measured in a sentence repetition task. In two others experiments we compared at the behavioural and electrophysiological level, the effect of a rhythmic training versus a classical linguistic or auditory training, on their speech production during a verbal interaction task with a virtual partner. We found that after 30 minutes of active rhythmic training, children fitted with cochlear implants were more sensitive to the rhythmic structure of the turn exchanges and their auditory system was more sensitive to temporal deviation of the virtual partner turns.

These results show that 1) rhythmic skills in children with CI need to be improved, particularly on complex rhythmic structures and 2) rhythmic training can have an effect on their speech perception and production capacities during verbal interactions.

**Title:** Evaluation of cochlear implant mediated music processing using electrodogram mapping to compare with perception

**Authors:** Aaron Hodges, Maurice Smith and Julie Arenberg

**Affiliations:** Mass Eye and Ear, USA

Appreciating and perceiving music has been a persistent challenge for cochlear implant users (CIs). Despite having speech perception capabilities in quiet environments, CI users struggle with foundational components of music like pitch discrimination and in many cases are unable to enjoy music to the same degree previously. This study seeks to provide a methodology to analyze the spectral differences between musical notes and instruments after processing by the cochlear implant. We hypothesize that comparing cochlear implant processed signals (electrodograms) of different musical instruments and notes will match the performance of cochlear implant users when tasked with distinguishing musical signals from one another.

In this study, we used an electrodogram analysis to visualize and quantify musical signals processed by a 16-channel cochlear implant speech processor using the Bionic Ear Programming Software (BEPS+) provided by Advanced Bionics. Signal processing strategies have previously been proposed to affect music perception, so we focused on two commonly used CI strategies: HiRes and Optima. We used wav files from the Clinical Assessment of Music Perception (CAMP) test that provided comparable pitch and timbre between common instrument families. We additionally sampled 2 other sources of the same instruments and notes to compare signal processing strategies. A correlogram was computed comparing the electrodograms representing musical notes and the notes within an instrumental group was used to quantify the similarities and differences of the electrodograms. This provided an overall correlation, determining which instrument and/or note was predicted to be the most distinguishable from the others.

We found that lower frequency notes from the CAMP sample instruments had lower correlations. When comparing different instrumental groups, the clarinet had the lowest correlation, and the trumpet had the highest correlation. A two tailed, two sample t-test comparing HiRes and Optima on the multiple samples of instruments on the same notes as the CAMP study ($n=24$) was $p=0.0190$ with Optima having the lower correlation. When comparing multiple samples of the notes ($n=15$) the t-test showed $p=0.0445$ with HiRes having the lower correlation. A lower correlation suggests potentially better discrimination of instruments and notes.

Our analysis demonstrated that lower frequency notes are likely more distinguishable than higher frequency notes, which is expected considering CIs only process sounds up through 8 kHz. Our results were similar to the findings of the original CAMP study (Nimmons et al.) but may differ slightly due to some difference between our correlation analysis and human perception during a note or instrument identification test. We demonstrate that electrodogram and correlation analyses are a way towards fine-tuning the listening experience for CI users and may provide insight into what changes to musical signals could have the greatest impact on improving distinguishability of notes and instruments.

**Title:** Differences and similarities in pitch discrimination and timbre recognition between Danish children with bilateral hearing aids or bilateral cochlear implants and children with normal hearing.

**Authors:** Nille Kepp

**Affiliations:** University of Copenhagen, The Faculty of Health Science, Denmark

**Background:** Studies have shown that children with hearing loss (HL) using either cochlear implants (CI) or hearing aids (HA) have a poorer perception of pitch and timbre compared to children with normal hearing (NH). Many studies are characterized by clinical differences within the groups of study participants i.e. uni- or bilateral CI, use of HA before CI operation, age at HA fitting or CI activation, hearing age and communication mode. This study aimed at exploring whether the findings are representative for Danish children with HL using different hearing technology and children with NH. Our population have (ideally) received early medical and state-of-the-art bilateral technological intervention and in many cases several years of auditory verbal intervention. The variety of clinical differences in this group is therefore limited. Furthermore, socioeconomic factors are minimized as the different interventions are offered for free to all children with HL in Denmark. The first specific objective of this present study was to identify differences and similarities in pitch discrimination and timbre recognition abilities between children with HA compared with children with CI. The second specific objective was to compare the whole group of children with HL to a control group of children with NH. The third specific objective was to evaluate the clinical applicability of a virtual reality test tool in a pediatric population with HL.

**Methods:** A Cross-sectional and comparative study design was used involving Danish children aged 7 – 15 years with NH (N = 11) and children with HL (N=14 children with bilateral CI, N= 5 children with bilateral HA). Firstly, the children were tested once with a pitch direction discrimination task using a novel virtual reality tool especially developed for this study at the Audio Visual Immersion Lap at the Technical University of Denmark. Secondly, they were tested with the Timbre Perception subtest of the Clinical Assessment of Music Perception (the CAMP test) on a laptop. The performance of the two tasks were compared between the group of HA users and the group of CI users, and secondly compared between the whole group of children with HL and the group of children with NH.

**Results:** The group of children with CI performed poorer on both the pitch and the timbre task compared to the group of children with HA. The whole group of children with HL compared poorer on both tasks compared to the group of children with NH. However, despite minimal clinical differences within the group of study participants with CI and HA, there were still noticeable differences between the individual performances within the groups.

**Discussion:** Differences and similarities of performance between the study groups will be discussed together with observations about the clinical applicability of using a virtual reality tool in pediatric audiological testing.

**Title:** Social wellbeing and the role of music for children with hearing loss

**Authors:** **Chi Yhun Lo, Valerie Looi, William Forde Thompson and Catherine McMahon**

**Affiliations:** Macquarie University, Australia

**Background:** Children with hearing loss tend to have poorer psychosocial and quality of life outcomes compared to their typical-hearing (TH) peers—particularly in peer relationships and school functioning. Evidence from studies of TH children have suggested that group-based music activities are beneficial for prosocial outcomes and help develop a sense of belonging. Investigations for children with hearing loss are nascent, but preliminary findings from a few studies have suggested that group music activities may have similar benefits for children with hearing loss as well. Significantly, the effect of music on psychosocial outcomes has primarily been investigated at an anecdotal level.

This study explored the effect of a music training program on psychosocial and quality of life outcomes for children with hearing loss using standardised questionnaire measures. We hypothesized that music training would provide benefits for the domains of peer relationships and prosocial measures.

**Methods:** Fourteen children aged 6 to 9 years with prelingual sensorineural hearing loss (SNHL) participated in a 12-week music training program. Participation involved group-based face-to-face music therapy and access to online music apps. Using a pseudorandomized, longitudinal design; 9 participants were waitlisted and utilised as a passive control group. Psychosocial wellbeing and quality of life were assessed using the Strengths and Difficulty Questionnaire (SDQ), the Pediatric Quality of Life Inventory (PedsQL), the Hearing Environments and Reflection on Quality of Life (HEAR-QL), and the Glasgow Children's Benefit Inventory (GCBI). Comparative responses were also obtained from 16 TH children that ranged in age from 6 to 9 years.

**Results:** At baseline, children with SNHL had poorer outcomes for internalizing problems, and all measures of the HEAR-QL compared with the TH children. There were no differences for general psychosocial and physical health. After music training, SDQ internalizing problems such as peer relationships and emotional regulation improved significantly for the children with SNHL. There were no changes for any outcomes for the passive control group. Additional benefits were noted for emotional and learning factors on the GCBI. However, there were no significant changes for any psychosocial and quality of life outcomes as measured by PedsQL or HEAR-QL.

**Discussion:** The present study provides initial evidence that music training has a positive effect on some psychosocial and quality of life outcomes for children with hearing loss. As they are at a greater risk of poorer psychosocial and quality of life outcomes, these are positive findings with implications for rehabilitation practice. Children with hearing loss should be encouraged to participate in group-based musical activities.

**Title:** Optimized cochlear implant fitting to enhance singing voice in popular music

**Authors:** **Sina Tahmasebi, Marianna Vatti, Manuel Segovia-Martinez and Waldo Nogueira**

**Affiliations:** Medical University Hannover, Germany

Cochlear implant (CI) users have limitations in music appreciation caused by the poor pitch, timbre and dynamic perception they obtain. Previous research has shown that CI users enjoy music better when the singing voice or vocals are enhanced with respect to background instruments [Buyens et al., 2014; Pons et al.,2016]. This work investigates an optimization of the sound coding parameters offered by the Voice Guard processing scheme from Oticon Medical (Vallauris, Provence, France) to enhance the singing voice with respect to the background instruments in popular music. Three newly designed fitting parameterizations have been evaluated using objective instrumental measures and behavioral measures in subjects.

The effect of number of selected bands of the N-of-M processing step, the strength of the noise reduction algorithm and the compression settings of Voice Guard were investigated to enhance the singing in voice in music. The amount of singing voice enhancement was determined through an objective instrumental measure termed the vocals-to-instruments ratio (VIR). The VIR is computed at the level of the electrodogram by subtracting the estimated level of the vocals and the background instruments in dB. The backend compression algorithm Voice Guard has been re-designed to increase the CI electrical dynamic range in music. Percentile analysis was used to measure the dynamic range across bands in the music. The dynamic range is reported for the 30th, 65th, and 99th percentiles. 30 s segments of 20 commercial and popular music pieces (bass, drums, vocals and a group of other instruments) from the MUSDB data set were used in the measurements. Based on the analysis of the objective instrumental measures, three programs differing in their parameterizations with respect to the number of selected bands, strength of noise reduction and the use of the re-designed Voice Guard have been created.

The results from the objective instrumental measures demonstrate that the vocals can be enhanced with the respect to the background instruments by optimizing the sound coding parameters. The VIR measurement for the three defined fitting programs shows an electrical VIR improvement of up to 2 dB with the respect to a clinical fitting of the Oticon Medical sound coding strategy. The dynamic range was calculated as the difference between the 99th and 30th percentile across bands. The results from percentile analysis show a substantial improvement for the new parameterization in electrical dynamic range in comparison to the clinical settings of the Oticon Medical sound coding strategy.

The three programs are currently being evaluated in Oticon Medical subjects using a singing voice melody contour identification task, speech understanding with background instruments and music appreciation questionnaires.
Acknowledgments: Special thanks to Oticon Medical for providing the Oticon Medical stimulation chain and funding this project.

**Title:** How music training and singing improves the speech and language skills of children with hearing loss – MULAPAPU-project.

**Authors:** **Ritva Torppa, Seija Pekkala, Tiiti Eerikäinen, Ilona Siltanen and Valerie Looi**

**Affiliations:** Department of Psychology and Logopedics, University of Helsinki, Helsinki, Finland

**Background:** Previous research has shown that greater levels of participation in music activities which include singing is associated with better speech perception and language skills for children with cochlear implants (CIs). The current project (MULAPAPU) collects evidence on the effect of music intervention and investigates why particularly singing would have an effect on these skills.

**Methods:** This project is in progress (2019-2022). The participants are children aged 1-6 years with bilateral implants, bilateral hearing aids, or bimodal, and normal-hearing (NH) controls. The 10 weeks music intervention (45 minutes per week, with singing at home) is led by speech therapy and music pedagogy students/professionals, conducted partly face-to-face, and partly through video-conferencing. Information on, e.g., musical, language and musical skills is collected with questionnaires. Data is collected remotely for: semantic word fluency, naming (picture naming and rapid naming), nonword repetition in segmental and suprasegmental level, auditory working memory, discrimination of acoustic cues for word stress, and singing accuracy. For children with hearing loss (HL), these measurements are conducted three times (cross-over design: half of children start with waiting, half with intervention period, the latter have waiting period after intervention). Optical imaging (fNIRS) data will be collected once. The present sample for word fluency task (number of accepted names of animals) includes 14 children HL and 12 with NH.

**Results:** Preliminary results comparing children with HL and their NH peers in the word fluency performance showed that the differences between groups were not significant. However, for children with HL, singing was linked to better performance. Before intervention, after controlling for age, the children who sang daily and/or whose parents sang more for them at home outperformed those children who sang/whose parents sang less. During music intervention period, only the poorer performing, less-singing children developed. Maternal education or hearing device (CI vs. HA) was not linked to the development. More preliminary results will be presented in the symposium.

**Discussion:** The results indicate that the singing habits of the parents and children themselves before intervention play a role in the effects of intervention at least on word fluency performance. Singing before intervention may lead to a ceiling-effect (very good performance), and therefore the music intervention used in this study only demonstrated a significant effect for poorer performing children who sang less at home. More data collection is needed and many aspects have to be taken into account before the final results can be seen.

**Acknowledgements:** We wish to thank the Signe and Ane Gyllenberg Foundation for funding the MULAPAPU-project, LapCI ry for organizing and STEA (Funding Centre for Social Welfare and Health Organisations) for funding the speech-music groups.

**Title:** Discriminative abilities of young children in music one and two years after cochlear implantation: an EEG study.

**Authors:** **Niki K. Vavatzanidis, Nina Siefke, Alexander Mainka, Dirk Mürbe and Anja Hahne**

**Affiliations:** Technische Universität Dresden, Germany

**Background:** Children with cochlear implants (CIs) show on average a remarkably good language development when implanted at a young age. Less is known of their ability to process musical elements, though several musical features intersect with linguistic features (e.g. vowel lengthening and tone duration). From adult CI users we know that a satisfactory speech comprehension via the CI often does not translate into an enjoyable music experience with the implant. For infants and toddlers on the other hand who receive their implant at a very young age when the brain and the auditory system is highly plastic, we know little about their ability to process musical features.

**Methods:** We recorded EEG data of children 12 months after bilateral cochlear implantation (N=18; median age at testing: 27 months) and of 12-month-old typically hearing children (N=28), i.e. a control group with the same amount of hearing experience. Additionally, a group of children 24 months after implantation (N=14) were recorded to evaluate developmental changes over time. All children were tested with a multi-feature mismatch negativity paradigm adapted from Vuust et al. (2010). The standard stimulus consisted of a four-tone sequence with an acoustic piano timbre (Alberti bass) played in all 12 major and all 12 minor scales. To elicit the mismatch negativity (MMN), the 3rd tone of the standard stimulus was altered in five different dimensions: pitch (+50 ct for minor scales and -50 ct for major scales), timbre (acoustic piano -› old time radio), intensity (-9 dB), rhythm (-25ms onset) and slide (triole with -25ms onset).

**Results:** First results suggest that children perceive no deviations from the standard stimulus after the first year of CI use. This changes during the course of the second year, when CI children show significant differences for timbre and slide deviants, the latter being the most prominent deviant, but do not perceive the differences in pitch and intensity that were successfully detected by typically hearing children. The increased hearing experience after two years of CI use also leads to higher overall amplitudes that more closely resemble the nature of the ERPs of the typically hearing control group, thus demonstrating increasing maturation.

**Conclusions:** Developing the discriminative abilities needed for music with a CI is a gradual process that is by no means complete after one year and possibly not even two. Knowing this might help managing expectations in parents but also in adult CI users. Since pitch and intensity were the features hardest to detect in our study, we suggest that prosodic aspects of language might also require more time to be “fully” perceived within an individual child’s CI hearing abilities.

**Title:** Audio-tactile interaction in timbre: Effect of tactile stimulation on auditory temporal envelope perception

**Authors:** Tushar Verma, Scott C. Aker and Jeremy Marozeau

**Affiliations:** Technical University of Denmark

**Background:** The auditory system is just one of the pathways that form our sense of hearing. Therefore, it has been argued that hearing loss should be treated with a multimodal approach. In this study, we are investigating if an audio-tactile stimulus can create a stronger percept of timbre for hearing-impaired listeners. Cochlear-Implant users often report a degraded percept of timbre that could lead to a lower music enjoyment. If the perception of timbre could be altered by a vibrotactile stimulation, cochlear implant users could have a new path to potentially improve their music experience.

**Methods:** Temporal aspects of timbre, specifically impulsiveness and roughness (amplitude modulation) were studied to see if vibro-tactile feedback can affect or enhance auditory timbre perception. A multidimensional scaling experiment was conducted. Twenty-one normal hearing subjects and 9 subjects with cochlear implants were asked to judge the dissimilarity of a set of synthetic sounds where the attack time and the amplitude modulation depth of sounds were varied systematically. The subjects were also presented vibro-tactile stimulus of varied degrees of impulsiveness and amplitude modulation in conjunction with the audio stimuli. Six sets of complex audio samples were presented with four pairs of tactile stimuli each.

**Results:** Normal Hearing subjects: The results showed that despite the subjects being told to ignore the tactile stimuli, alterations to the temporal waveform of the tactile stimuli affected their perception of the audio. A 3-dimensional analysis revealed a cross-modal interaction where a combination of the audio and tactile equivalents accounted for their dissimilarity judgements. The first dimension was explained by the Audio (86%) and tactile (14%) impulsiveness. The second dimension was explained by the Audio (75%) and tactile (25%) Roughness. Interestingly, the 3rd dimension revealed a combination of the Audio impulsiveness (43%) and Tactile roughness (57%), essentially showing that the impulsiveness of a sound could also be increased by following it with a stronger tactile roughness. Cochlear implant users: The percept of CI users turned out to be 2 dimensional and one of the dimensions being solely dependent on the audio impulsiveness, while the other dimension could be explained mostly by the tactile roughness. Note the dominance of the tactile roughness, giving an indication that AM percept can be enhanced using tactile stimulation.

**Discussions/Conclusions:** This result shows that the judgment of timbre difference can be affected by a tactile input. It is also important to note that effect is cross-modal in nature and the qualities of the tactile stimuli effect the perception of audio and skew them depending on their nature. We also show that it is possible to restore the percept of roughness in CI with an audio-tactile stimulation. This could lead to new devices that might enhance the enjoyment of music.

# Posters

| Poster Category | Presenting Author | Title | |
|---|---|---|---|
| **Pitching it Right: Exploring Melody** | Jesper Andersen | Music and cochlear implants – a review | |
| | Russ Palmer | Cochlear implants, musical perception, and vibrosensoric musicality | |
| | Ryan Gray | Is there a musician advantage in speech-on-speech perception in older age? | |
| | Imke Hrycyk | Musical emotion categorization with simulated cochlear implant hearing | |
| **Mixing it Up: Listening Approaches for Enjoying Music** | Samuel Perry | Using the mosaicOne electro-haptic device to improve pitch perception for cochlear implant users | |
| | Andrew Chang | Amplitude modulation is crucial for categorizing noise-vocoded sounds as speech or music | |
| | Xin Luo | Sharp temporal onsets of piano notes improve musical emotion recognition with cochlear implants | |
| | Khaled Abdellatif | Sound quality assessment in bimodal cochlear implant users | |
| | Razvan Paisa | The relationship between vibrotactile actuator frequency and area of activation of the hand | |
| | Bastien Intartaglia | Intact sensorimotor rhythm abilities but altered audiovisual integration in cochlear implant users | |
| **Raising the Bar: Signal Processing Advances and Settings for Improved Music Listening** | ~~Shaikat Hossian~~ | ~~Perceptual differences between analog and pulsatile stimulation in a single-sided deafened patient~~ | Retracted |
| | Pierre Stahl | Utilizing objective measures to assess musical feature distortion processed with different cochlear implant sound processing strategies | |
| | Mustafa Yuksel | Preliminary findings on the mistuning perception in cochlear implant recipients | |
| **Practice makes Perfect: Music Training Approaches, Benefits and Limitations** | ~~Barbara Kaczynska~~ | ~~Use of original music compositions in therapy for children with cochlear implants within the "Instrumental Theatre" – preliminary report~~ | Retracted |
| | Charlotte Thostrup | MusiC Ideas – for teaching adult cochlear implant users to enjoy listening to music again | |
| | Charlotte Thostrup | Auditory training program for music perception for adult cochlear implant users | |
| | Kavassery Venkateswaran Nisha | Does musical training confer differential advantages in binaural integration and interaction tasks? A comparative study on instrumentalists and vocalists | |
| | Busra Yilanli | Effects of the music training program for children with cochlear implants | |
| | Amineh Koravand | Preliminary study of the effects of piano training in children with hearing loss | |
| | Eleanor Harding | Guided audiomotor exploration (GAME): Improvisation-based instrumental music training for cochlear implant users | |
| | Marianna Vatti | Games for music training for cochlear implants | |
| | Krzysztof R. Szymański | Long-range systematic training of the melodic contour | |
| Making Sense of Music: Brain Mechanisms that underpin Music Listening | Aashish Sharma | Exploring déjà entendu: a comparative study between musicians and non-musicians | |
| | Cheuk Chee Cynthia Lam | Does the quality of pre-implant hearing experience relate to post-implant music listening experience? | |
| | Christine Rocca | Music in the mind | |
| | Bjørn Petersen | MMN as a reliable marker of music discrimination in individual cochlear implant users | |
| | Alberte B. Seeberg | Adapting to the sound of music – development of music discrimination skills in recently implanted cochlear implant users | |

# Pitching it Right:
## Exploring Melody

**Title:** Music and cochlear implants – a review

**Authors:** Jesper Andersen and Stefania Serafín

**Affiliations:** Aalborg University and The Royal Danish Academy of Music, Denmark

**Background:** Research in sound perception by users of Cochlea Implants (CI) has, since the 1960s, focused on perception of speech. From 1990s a growing interest in music perception arose and from the 2000s much more research within music perception for CI has taken place. In the last decade, a growing number of music professionals and researchers within audio-processing and VR has shown interest in music and CI. Notable research reviews are some years old – McDermott (2004), Looi (2008) Looi et al (2012) – so there is a demand for a new extensive review, which is what will be presented here. This review will differentiate itself from earlier reviews by having a viewpoint from the field of music and will be especially aimed at readers in this field.

**Methods:** A review of 350 research projects/articles is carried out and. The reviewed research originates from 1970-1999 (27), 2000-2009 (138) and 2010-2021 (185). The number of articles and their primary topics are outlined here: General CI-articles/reviews (30), CI-users, listening habits, appreciation (30), CI-construction, processing, modalities (59), Test methods (15), Broader music perception (25), Pitch, melody, intervals (75), Timbre (15), Rhythm (5), Dynamics (5), Localization (18), Voice, singing (10), Masking/segregation (10), Emotion, tension (12), Pre-processing (13), Music composed for CI (4), Simulation (4), Other sensory inputs (5), Musical training (15)

**Results:** After a historic background and technical description of CI's is presented, CI-users are described as a highly differentiated group – both in relation to listening capabilities, habits and music appreciation. The primary part of the article covers music perception for CI-users. Here, it is shown that a broad and mutual pattern of perception for CI-listeners does not exist, for instance when topics like pitch/timbre-confusion and place vs. rate coding are introduced. Finally, research on pre-processing, simulation, training and music composed for CI is covered. To give a clear overview, the review of findings will be organized into the topics listed above – each with an introduction, findings and short discussion.

**Discussions/Conclusions:** The review will give an overview of research in music perception for CI-users. This will help music professionals understand and work around these limitations while researchers can be inspired for further work. Especially, it will be beneficial to understand the limited and highly differentiated listening capabilities of CI-users. And while there are many limitations, music appreciation is still very possible.

**Title:** Cochlear implants, musical perception, and vibrosensoric musicality

**Authors:** **Russ Palmer and Stina Ojala**

**Affiliations:** Andante research group, Tampere University, Finland

Musical perception for cochlear implant (CI) users may be experienced in different forms. This includes music listening, appreciation, singing and performing. Combining feeling music through the body and listening through CIs (vibrosensoric perception) allows one to experience music holistically.

Rehabilitation and developmental process: Co-operation with audio scientists during rehabilitation requires adaptations to appreciate different musical soundscapes. CI programme maps need to allow specific adjustments to meet both speech and musical perception. There may be specialised programmes for various sound environments (quiet, noise, music, performance). Familiar musical soundscapes that may have been heard before the implantation will enable the CI users to retrain to the new sound landscapes. That is, they will need to adapt to the familiar sounds in a new way. This readaptation process requires motivation and confidence over a specific time period. CI users have their individual tastes for different music styles. Introducing minimalistic styles of music would enable CI users to retrain and interpret simplistic soundscapes which build up into wider ones. Furthermore, familiar music that may have been heard before the CI may introduce new sounds which have not appeared in the user's hearing soundscape due to the difference in frequency bandwidths they perceive with CIs. New sounds may start to come through with the CIs and in some cases the new sounds will change the way the user appreciates the music styles. Also, one needs to identify the role of music in speech rehabilitation – especially in rhythm and intonation training as well as building confidence in exploring your own voice, dialect and cultural heritage. This is where music therapy is a good support for the rehabilitation process.

Listening and performing music: Listening to music and performing on stage requires a vibrosensoric approach to music. This is feeling and hearing the music. Residual hearing may have been developed in the past hearing aid experience, which can be expanded through the CIs. During a live concert a person perceives musical tones and vibrations through the acoustic environment, fixed furniture and surfaces. This is the essence of vibrosensoric experience. During a performance with a CI user in a group, positioning of the players may require specific adjustments as well as adjusting intensity and sensitivity levels of the CIs. In addition, one might use a brimmed hat to balance the sound environment further.

**Conclusions:** Through combining various methods and approaches CI users will have a richer, broader soundscape and musical experience. In some cases it may improve the individual's participation and inclusion in the society.

**Title:** Is there a musician advantage in speech-on-speech perception in older age?

**Authors:** Ryan Gray[1,2], Laura Rachman[3,2], Etienne Gaudrain[4,3], Anastasios Sarampalis[1,2], Eleanor Harding[3,2], Deniz Başkent[3,2]

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Previous research has suggested that musicians have an advantage over non-musicians when understanding speech in noise, especially for speech-on-speech perception. However, this advantage has mostly been observed in younger adults and it is not yet known if such an advantage extends to older adults. Similarly, the mechanisms that underpin any musician advantage are still debated. For instance, it remains unclear to what extent the observed musician advantage in speech-on-speech perception is due to gains at the perceptual level (such as pitch perception), and/or cognitive advantages (such as better working memory capacity). Both of these could be affected by the ageing process, resulting in different cross-domain effects from musical training to speech perception.

This study therefore aimed to explore whether older musicians perform better than older non-musicians during a speech-on-speech perception task. Older adults aged 60 years and above, with self-reported normal hearing, were recruited and took part in an online version of the Dutch Coordinate Response Measure (D-CRM) in their own home. This task required participants to recall key words (numbers, colours) from a target, spoken sentence, when masked by another gibberish speech stream spoken by a single speaker. This also ensured that there was no interference at the semantic level. Musicianship was defined using the common and standard criteria reported in the extant literature. To determine whether any observed musician advantage in older age is governed by improved pitch perception, we manipulated the vocal pitch of the masker speaker relative to the target, to create three different voice conditions. This was done so by altering the fundamental frequency (F0) and vocal tract length (VTL) of the masker speaker together, which allowed us to measure whether any differences in performance varied depending on differences in speaker pitch. Analyses were conducted to investigate the differences in target accuracy between musicians and non-musicians. Preliminary findings indicate that older musicians outperformed older non-musicians across all conditions, though this did not reach significance with the limited data we have. . Overall, the results suggest that musical training is associated with better speech-on-speech perception in older age, a skill important to maintaining successful social interactions. This advantage was not governed by improved pitch perception, rather some other mechanism, possibly better working memory capacity. Should this be the case, these improvements could also translate to a number of other skills important to successful ageing.

**Title:** Musical emotion categorization with simulated cochlear implant hearing

**Authors:** **Imke Hrycyk; Etienne Gaudrain; Barbara Tillmann; Robert Harris; Bert Maat; Rolien Free; Christina Fuller; Eleanor Harding & Deniz Başkent**

**Affiliations:** University of Groningen, University Medical Center Groningen, Department of Otorhinolaryngology, Groningen, Netherlands

The ability to hear and appreciate music is crucial to everyday cultural participation and likely contributes to quality of life. Among cochlear implant (CI) users, it is therefore important to not only restore the perception of speech, but also of music. Research has shown that CI users generally report sub-optimal enjoyment for music, and exhibit a high heterogeneity in their perceptual performance, often measured with recognition of melodies and pitch deviations. The present study investigated potential effects of degraded sound, as it can occur in CIs, on the perception of emotions when listening to classical music. In particular, we manipulated carrier type (sine, noise), and filter order (4th, 12th) to simulate different levels of spectral resolution. The musical stimuli conveyed one of four emotions (joy, sadness, fear, serenity), which were chosen to correspond to high and low levels of arousal, and to positive and negative valence. The discriminability of each emotion was estimated through the sensitivity index (d') and from the response bias (c).

Data indicate firstly that categorization accuracy was above chance level for all experimental conditions. Secondly, both vocoder parameters produced significant main effects, suggesting that better music emotion categorization was observed with a sine carrier rather than a noise carrier, and a steeper filter rather than a shallower filter. Thirdly, in degraded conditions, the error pattern exhibited by the participants was systematic rather than random. A subsequent feature-information-transmission analysis indicated that information about the arousal were predominant in the decision process, while valence was not transmitted properly. These results were also reflected in the analysis of d' and c, which showed a higher discriminability for joy and fear, both emotions of high arousal, and a bias against sadness and serenity, both emotions of low arousal.

To summarize, it seems that participants benefited from pitch-related cues provided by the sinusoidal carrier and from increased signal clarity provided by steeper filters. The simulation results, thus, imply that this task can be taken by CI users, but spectral resolution and transmitted pitch cues will likely play a determining role. Importantly, while valence information was not recognizable in the manipulated signal, arousal information seemed to be preserved and available within all experimental conditions. It implies that, perhaps, emotional content of certain types of music, for example one with many arousal cues, could be more accessible for CI users than others, potentially contributing to improved music listening and enjoyment.

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# Mixing it Up:
## Listening Approaches for Enjoying Music

**Title:** Using the mosaicOne electro-haptic device to improve pitch perception for cochlear implant users

**Authors:** Samuel Perry, Nour Thini and Mark Fletcher

**Affiliations:** The University of Southampton, UK

Cochlear Implant (CI) users typically have limited ability to perceive melodic content in music, particularly in complex auditory scenes with multiple simultaneous instruments. This limitation can lead to considerably reduced music enjoyment. Electro-haptic stimulation (EHS) is a new area of research that augments the CIs by delivering sound information through haptic stimulation on the forearm. This has shown improved performance for areas such as speech perception1,2 and sound localisation3,4, and may offer an additional intervention to improve CI user's pitch perception.

This poster presents the mosaicOne B haptic neuro-prostheses and an accompanying pitch discrimination study. First, the development of both the forearm-mounted device and accompanying signal processing strategies for converting acoustic signals to haptic stimulation are detailed. Second, a study is presented exploring the viability EHS to improve simulated CI user's (normal hearing listeners using a simulated CI) ability to discriminate pitch differences for harmonic complexes in increasing background noise. Results of this study show simulated CI users were able to discriminate harmonic complexes differing in pitch by as little as a semi-tone, with performance maintained in inharmonic background noise of up to -7.5dB SNR5.

The results presented suggest there is clear potential for EHS to improve pitch and melody perception for CI users. Further work is needed to establish the most effective device configuration, to optimise the signal-processing strategy, to evaluate the approach on more ecologically valid stimuli, such as musical excerpts, and to address more complex scenarios such as excerpts with multiple harmonic sounds (such as tonal instruments). Overall, this technology could offer a method to improve CI user's music perception, by providing tactile stimulation for auditory cues that are poorly processed by CIs.

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**Title:** Amplitude modulation is crucial for categorizing noise-vocoded sounds as speech or music

**Authors:** **Andrew Chang, Xiangbin Teng, M. Florencia Assaneo and David Poeppel**

**Affiliations:** New York University, USA

**Background:** Despite our increasingly rich understanding of how humans process speech and music, surprisingly little is known regarding with different amplitude modulation (AM) rates. From the perspective of acoustics, the properties of the signals can be differentiated. Specifically, the AM rate of speech peaks between 4 and 5 Hz, while the AM rate of music tends to be slower, emphasizing modulation rate around 2 Hz (Ding et al., 2017). In addition, it is often argued that the AM of music tends to be more temporally regular or isochronous than speech (Kotz et al., 2018). For cochlear implant users, AM of the sound is a relatively intact auditory information and is heavily relied on when perceiving speech and music. Based on these insights, we hypothesized that the AM temporal features of an acoustic signal, especially their peak rate and regularity, are critical factors that determine whether a signal will be categorized as speech or music.

**Methods:** Here we parametrically manipulated (i) the AM peak frequency (0.6 – 6.0 Hz) and (ii) the AM regularity to generate a variety of signals with varying AM envelopes. The AM envelopes were synthesized with broadband low-noise noise carrier sound. Each stimulus is an amplitude modulated noise excerpt with manipulated AM features, equivalent to single-channel noise-vocoded sound. More than 300 participants have taken part in two online behavioral experiments. On each trial, they listened to one of the generated stimuli and were prompted to make a binary judgment on whether it sounds more like a “speech” or a “music” recording.

**Results:** The results support the hypothesis that, across participants, the sound excerpts with slower peak AM rate and more temporally regular AM were more likely to be judged as music. These factors appear to have around 36-50% of explanatory power, suggesting that the amplitude envelope alone is essential to differentiate speech and music. Furthermore, the stronger the music-speech/slow-fast AM association is correlated with higher musical sophistication of the participants.

**Discussions/Conclusions:** To the best of our knowledge, this is the first study showing that the AM temporal features are critical low-level factors of determining a sound to be interpreted as speech or music. This approach can be further deployed to study how music and speech are differentiated based on only their temporal features in cochlear implant users.

**Title:** Sharp temporal onsets of piano notes improve musical emotion recognition with cochlear implants

**Authors:** Xin Luo

**Affiliations:** Arizona State University, USA

In music, emotion is conveyed by mode (major or minor) and tempo (fast or slow) cues. To recognize musical emotions, normal-hearing (NH) listeners mainly use mode cues (i.e., pitch scales), while cochlear implant (CI) users rely heavily on tempo cues, because CIs do not convey salient pitch cues. Our previous study found a significant effect of instrument timbre on CI users' musical emotion recognition, with a piano producing better performance than a violin. Piano notes have sharper temporal onsets than violin notes. CI users may use such temporal envelope cues to identify the two instruments. It is hypothesized that sharper temporal onsets of piano notes may also enhance the perception of tempo cues and thus improve musical emotion recognition with CIs. This hypothesis was tested in this study.

Eight post-lingually deaf adult CI users with ten implanted ears were tested. For bimodal CI users, hearing aid was turned off and an ear plug was inserted into the non-implanted ear. For bilateral CI users, each implanted ear was tested separately. Eight NH adults served as the control group. Ten happy and ten sad melodies played by a piano and a violin from our previous study were used to create instrumental chimeras by combing the temporal envelope (ENV) of one instrument with the temporal fine structure (TFS) of another instrument for each melody. Piano, violin, TFSpiano-ENVviolin, and TFSviolin-ENVpiano melodies were tested in separate blocks for a two-alternative (happy or sad), forced-choice musical emotion recognition task. The testing order of instrument blocks and that of melodies in each block were both random. In addition, the four types of melodies were randomly played from trial to trial for a two-alternative (piano or violin), forced-choice musical instrument identification task.

The results showed that NH listeners' performance of musical emotion recognition was near perfect in each melody condition. NH listeners perceived TFSpiano-ENVviolin and TFSviolin-ENVpiano melodies to be played by piano and violin, respectively. CI users had significantly better musical emotion recognition for piano melodies than for violin melodies, consistent with our previous finding. For CI users, TFSviolin-ENVpiano melodies produced significantly better musical emotion recognition than violin melodies, while TFSpiano-ENVviolin melodies produced significantly worse musical emotion recognition than piano melodies. CI users had near perfect musical instrument identification for piano and violin melodies. Their instrument identification responses were 70% violin and 30% piano for TFSviolin-ENVpiano melodies, and 35% piano and 65% violin for TFSpiano-ENVviolin melodies.

These results suggest that NH listeners use temporal fine structure cues to achieve robust musical emotion recognition and instrument identification. In contrast, CI users rely more on temporal envelope cues to perform both tasks. It was the sharper temporal onsets of piano notes that produced better musical emotion recognition for piano melodies than for violin melodies.

**Title:** Sound quality assessment in bimodal cochlear implant users

**Authors:** **Khaled Abdellatif, Verena Mueller, Horst Hessel, Martin Walger and Hartmut Meister**

**Affiliations:** Jean-Uhrmacher-Institute for Clinical ENT-Research, University of Cologne, Cologne, Germany.

**Objectives:** Many cochlear implant (CI) recipients use a hearing aid (HA) on the non-implanted ear. Current fitting rules of HAs are optimized on speech rather than music as input. However, a potential improvement might be the transmission of low-frequency acoustic sounds particularly targeting the requirements of music signals. In this project bimodally fitted CI-users are presented with music stimuli that are modified in a standardized and controlled manner and their individual sound quality judgements are collected. The goal is to find possible mechanisms that may be used for HA optimization based on either an individual or generic level.

**Design:** Non-linear signal processing of the acoustic path is simulated based on the individual pure tone audiogram of the participant using a generic fitting rule. Stimulation is provided by a HA receiver and the CI path transmits the unmodified stimulus via bluetooth to the subject's speech processor. The stimuli consist of acoustic only, electric only, and combined transmission considering several modifications of the acoustic path. Modifications are based on discrimination experiments conducted with the listeners. The MUlti Stimulus test with Hidden Reference and Anchor (MUSHRA) is used to assess sound quality for different stimuli such as classic and pop music with or without lyrics. Outcome of the assessments is determined regarding test-retest reliability, discrimination ability and agreement via the expertise Gauge (eGauge).

**Results:** Here we illustrate the methodology and present our first outcomes of the study.

**Conclusions:** Based on preliminary results the method seems generally suited for assessment of sound quality in bimodally fitted CI users and for providing information of optimized HA fitting.

**Title:** The relationship between vibrotactile actuator frequency and area of activation of the hand

**Authors:** Razvan Paisa, Niels Christian Nilsson and Stefania Serafin

**Affiliations:** Aalborg University, Denmark

**Background:** This experiment is part of a project that aims to build handheld devices for cochlear implant (CI) users. The work focuses on single-actuator, high-fidelity vibrotactile devices to be used by the target group when listening to music. It aims to demonstrate that distinct vibrotactile frequencies excite different areas of the hand with varying intensity. While it has been known that vibrotactile perception fits a critical band description [1, 2], it has not been determined if the sensations are perceived similarly across various skin areas.

**Methods:** This particular experiment is an exploratory study sparked by the informal findings from previous observations, specifically, the relationship between the frequency of the vibrotactile actuator and the area of hand where users perceived said vibrations. This goal translates into the following hypothesis: People perceive distinct frequencies in different areas of the hand (thumb, fingers, palm, wrist, etc), when using a single-actuator vibrotactile handheld device producing a constant amplitude oscillation at supra threshold levels. Furthermore, the relationship between frequencies and their respective areas of perception was investigated. The aim is to unearth a potential mapping between vibrotactile frequency and excited hand area, that could be explained by the local density of Pacinian corpuscles. An within-subjects design was conducted with 35 participants (25M, 10F), that required participants to report areas of most perceived sensation. The experiment had a multi-alternative (28) three forced choice design generating ordinal data, that represents areas of the hand. The device used can be seen in Figure 1, and it was build around a Haptuator BMXC1. The stimuli presented was first compensated according to the frequency response of the handheld device and then calibrated for constant supra threshold level (reference = 250Hz) with a cascade of 2nd order Biquad filters with F0 described in [3]. There were 11 frequencies presented, from 15Hz to 865Hz, separated by a major third interval.

**Results & Discussion:** Initial results show clearly that different frequencies excited distinct areas of the hand, especially at 171 Hz, 256 Hz and 384 Hz that are felt around the proximal phalanges while other frequencies are perceived on areas closest to the actuator's position(thumb area). Besides that, the perception of all frequencies seem to peak towards finger tips, as well as the palmar digital area. An in depth analysis is to follow (that will be presented in the poster) to understand how to correctly cluster areas into statistically meaningful zones (fingers, phalanges, etc) and to conclude whether a frequency-area mapping can be extracted from this experiment.

http://tactilelabs.com

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# Raising the Bar:

## Signal Processing Advances and Settings for Improved Music Listening

**Title:** Perceptual differences between analog and pulsatile stimulation in a single-sided deafened patient

**Authors:** **Shaikat Hossain**

**Affiliations:** Grainshifter, USA http://grainshifter.com

The present case study investigates differences in the perception of melodic intervals and timbre in a patient with an Advanced Bionics HR90K Advantage implant with normal-hearing on the other ear. The experimental procedure involved rate discrimination training with melodic contour identification (MCI) testing on a single electrode where the stimulation rate was varied to deliver temporal pitch cues. Three different baseline stimulation rates were employed (220, 440, and 880 pulses per second) to assess rate discrimination and MCI performance at different octaves. Three different stimulation types were included in the study (sinusoidal analog stimulation, unmodulated pulse trains, and amplitude modulated pulse trains). Quality was assessed as how similar the electric stimuli sounded to tones of the same frequency presented in the acoustic ear. The adaptive tracks were analyzed for each different stimulation type to assess whether there may be an advantage of a particular stimulation type for rate discrimination training. Preliminary results suggest differences in sound quality between analog and pulsatile stimulation.

Retracted

**Title:** Utilizing objective measures to assess musical feature distortion processed with different cochlear implant sound processing strategies

**Authors:** **Pierre Stahl, Yue Zhang, Marianna Vatti and Manuel Segovia-Martinez**

**Affiliations:** Oticon Medical

Cochlear implants (CIs) are devices able to recover auditory sensations by analysing sound features, recomposing, and coding them into series of electrical pulses directly into the inner hear. Although the earliest CIs were first aimed to compensate partially for a totally lost auditory function, the modern multichannel has improved and is able to reach up to perfect scores of speech perception in simple auditory scenes. Research is now focusing on improving hearing performances from more complex auditory scenes and part of the effort has been direct towards the perception of music, which remains unsatisfactory for the most. Melodies are hardly recognized without rhythmic cues, and timbre is not perceived. The reasons for such discrepancies are multiple. The CI hardware may not embed enough electrodes, coding strategies may be improved, signal processing is not flexible enough to provide the fine analysis melodic sounds requires. Next generation of CIs may benefit from the evolution of new technologies that may resolve some of the issues cited above, more flexible pulse generation, higher density of electrode contacts, smaller electrodes, etc. Most signal detection processing will be outdated (e.g. Fast Fourrier Transform or IIR/FIR Filterbanks – FB), limiting the CI either by their calculating power consumption (FB) or their frequency resolution (FFT). Already existing CI devices may already benefit from new signal processing technology to encode precisely melodic features. The Spectral Feature eXtraction (SFX) is able to accurately detect features over more than 60 channels, all in having low calculation power. The SFX combines the signal information from double Short Time Fourrier Transform (SFTF) to recreate the signal energetic components the closest possible to the original signal with no channel limitation.

This study evaluates the capability for sound processing systems to decompose music signals before information is being coded into pulses for the CI. For that, music sounds will be passed through the three different processing strategies (SFX, FFT or FB), reconstructed and analysed with the Music Information Retrieval toolbox (MIR), designed to detect features from musical signals. The results of each MIR analysis are passed through a dimension reduction method to extract the principal robust components that are constituting the sounds. For the most prominent features being identified, a parametric statistical model is then used to investigate how the processing strategies affected the feature composition of the processed reconstructed musical sounds, with respect to those of the original. The aim of this study is then to estimate and compare the level of feature distortion of the processed sounds with respect to the original.

**Title:** Preliminary findings on the mistuning perception in cochlear implant recipients

**Authors:** **Mustafa Yuksel and Deniz Başkent**

**Affiliations:** Research School of Behavioural and Cognitive Neurosciences, University of Groningen, The Netherlands

**Background:** Music is an essential art form that can evoke strong emotions and, the harmonious presence of the human voice in music can transform strong emotions and meaning. As a result, vocal music had some significant impact and presence in modern music. Cochlear implant (CI) recipients have some difficulties in different aspects of music; however, it is not known how well they perceive vocal tuning in music. Hence, this study aims to evaluate the mistuning perception of CI recipients and compare their performance with normal-hearing listeners.

**Methods:** 13 postlingually deafened CI users (7 cisgender males, six cisgender females) and gender-matched controls with normal hearing with an average age of 30.6 years (±9.1, range = 19-49) and 23.5 years (±6.1, range = 20-37), respectively were participated in this study. All CI recipients were unilateral users and, 5 of them had a hearing aid in their contralateral ear. None of the participants had any formal music training besides regular school curriculum. We evaluated the mistuning ability using the mistuning perception test (MTP) that was developed and validated recently by Larrouy-Maestri, Harrison and Müllensiefen. The MTP is an adaptive two-alternative forced-choice task testing the discrimination between a pitch-shifted and unaltered version of the same short musical excerpts. Participants instructed to determine the “out of tune” excerpt between the two. Each test started with detailed instructions and a two-trial training session. Testing continued with the actual test that included 15 trials. Test performance was measured and reported on the item response theory metric with a z-score ranging from -4 to 4. Testing completed in an acoustically treated room at a comfortable listening level.

**Results:** CI and NH groups scored -1.454 (±0.786, range = -2.597 to 0.211) and 0.146 (±0.808, range =-1.413 to 1.718) in the MTP test, respectively. The difference in the MTP test between groups was statistically significant ($p = 0.0004$). Compared to the validation study where 95% of participants performed between -1.369 and 1.136, the CI group performed below, while the NH group performed similarly to these values.

**Discussion/Conclusion:** The present study shows that vocal tuning perception is another limitation in music perception for CI recipients similar to previously evaluated aspects of music perception. Considering the importance of vocals in the perception and enjoyment of modern music, this aspect should be considered in the assessment of music perception, enjoyment, and music-based auditory interventions in CI recipients. Larrouy-Maestri P, Harrison PMC, Müllensiefen D. The mistuning perception test: A new measurement instrument. Behav Res Methods 2019;51:663-75

**Title:** Intact sensorimotor rhythm abilities but altered audiovisual integration in cochlear implant users

**Authors:** **Bastien Intartaglia, Nicholas Foster, Marie-Anne Prud'Homme, Sylvie Nozaradan and Alexandre Lehmann**

**Affiliations:** Department of Otolaryngology Head and Neck Surgery, McGill University, Montreal, QC, Canada

**Background:** Cochlear implants (CIs) are neural prostheses that can restore hearing in the profoundly deaf. The degraded pitch resolution provided by CIs corresponds with worse performance on tests of pitch and musical melody perception, while the largely intact temporal resolution of CIs may be sufficient for rhythm perception. However, few studies have focused on auditory rhythm perception in CI users. Additionally, there is evidence of neural reorganization resulting from pre-implantation deafness, with impact on visual perception and multisensory/ sensorimotor integration. This crossmodal plasticity may be maladaptive after implantation, but its effect on visual or auditory rhythm abilities in CI users is not yet known. The aim of this study was to measure both unimodal and multimodal auditory and visual abilities in CI users compared to normal hearing (NH) controls using a standard sensorimotor synchronization paradigm.

**Methods:** A total of 20 CI users (5 male; 5 pre-lingual; age 19-65, mean 43.2 years) and a matched group of 18 NH controls were tested on a temporal finger tapping synchrony task with 4 isochronous stimulus conditions: an auditory metronome, a visual metronome (flashes), a synchronous presentation of both the auditory and visual metronomes at the same tempo, and an asynchronous presentation of the auditory and visual stimuli at differing tempos. In the multimodal conditions, participants were instructed to tap to the visual stimulus. Participants performed 10 trials on each condition, each having a duration of 39.5 seconds. Synchronization consistency was calculated via circular statistics, using the logit of vector length. Effects of group and task condition on synchronization scores were analyzed using a mixed-effects model.

**Results:** For both CI and NH, unisensory synchronization to auditory stimuli was better than for visual stimuli. Performance on the visual condition was equal between groups, and there was a trend toward greater advantage for auditory over visual synchronization in NH compared to CI. When multisensory auditory timing was congruent with visual timing (synchronous condition), performance increased over unisensory visually paced timing for NH but not CI. The effect of interference from incongruent auditory information in the asynchronous condition was equivalent in NH and CI.

**Conclusions:** The results show intact ability to synchronize with auditory stimuli in CI users, with greater temporal precision than for visual stimuli. This matches the pattern in NH, but the unisensory auditory advantage may be diminished in CI. We find evidence for altered multisensory integration of congruent audiovisual input in CI, i.e. diminished improvement from auditory information during visually paced synchronization, but no difference compared to NH for multisensory interference. Together, this study provides evidence that auditory temporal perception remains largely intact in CI users, while audiovisual integration is altered. Future work will examine the neural bases of these differences.

## Practice makes Perfect:

## Music Training Approaches, Benefits and Limitations

**Title:** Use of original music compositions in therapy for children with cochlear implants within the "Instrumental Theatre" – preliminary report

**Authors:** **Barbara Kaczynska, Katarzyna Godlewska, Marzena Warsicka-Kaczynska and Henryk Skarzynski**

**Affiliations:** Institute of Physiology and Pathology of Hearing

**Introduction:** The aim of music therapy offered in the World Hearing Center, within the original program "Music in Human Auditory Development", based on active music concerts and passive music concerts, is to accelerate rehabilitation and auditory development for people with various hearing implants, as well as, their adaptation in the society. This process aims to allow patients to regain lasting and natural functioning in social, cultural, and professional lives. The task of therapeutic musical activities is to shape and improve the overall auditory and cognitive development, positively influencing various areas of patients' lives, especially in children.

**Objective:** This study aims to present the results of the preliminary assessment of music therapy classes conducted using instrumental and vocal compositions for the cochlear implants users, based on a three-month observation. Analysis of music therapy results was performed following the World Hearing Center's original indicator to assess music perception quality in cochlear implant users.

**Resources and Methods:** The study was conducted with 5 patients, aged 8-11, who have undergone cochlear implant surgery. The group was tested before the start of music therapy classes and after three months of classes which used active music concerts and stimulation with passive music concerts. The foundation for the original approach to the therapy were novel music compositions called 'Instrumental Theatre'.

**Results:** The study results indicate that music therapy designed according to the original program, significantly influences the development of auditory functions, especially sound identification and auditory memory. According to the observations conducted by music therapists from the World Hearing Center, patients who participate in the classes are much more engaged when listening to music and engaging in other traditional post-surgical rehabilitation processes.

**Preliminary Conclusions:**
1. Scarce academic literature and very few clinical resources indicate the need for a further effective search for original music compositions to be used in music therapy for children with cochlear implants.
2. For a more comprehensive assessment, the program needs to be continued and results compared after 6 and 12 months of the music therapy process.

Retracted

**Title:** MusiC Ideas – for teaching adult cochlear implant users to enjoy listening to music again

**Authors:** **Charlotte Thostrup and Mathilde Lumbye Orry**

**Affiliations:** Specialcenter Roskilde Kommunikation, Denmark

**Background:** Music is an important part of people's lives and 60-70% of the cochlear implant (CI) users we meet at our rehabilitation center wish to be able to enjoy music. Recognition of complex sounds is limited in a CI and it can be challenging to enjoy listening to music (Marozeau, Simon & Innes-Brown, 2014; Gfeller et al, 2002). Specialcenter Roskilde Kommunikation (SCR) has therefore developed a rehabilitation program for CI-users so that they can learn to enjoy music. The program has had a good effect on the participating CI-users, who have improved their perception of music and achieved increased enjoyment when listening to music (Worsøe, Johansen & Thostrup, 2021). Other rehabilitation centers have shown interest in the program as there is no correspondingly described material in Denmark. Despite this interest as well as the presentation of the program on several occasions, the implementation in other rehabilitation centers has proved challenging. We have therefore experienced a need for developing a detailed description of the tools and methodologies we use.

**Objective:** Our purpose was to publish SCR's CI-music rehabilitation program as an inspirational material for teachers of adult CI-users in Denmark for them to use in their rehab practice.

**Method:** MusiC Ideas was developed by collecting and editing activities from SCR's CI-music program over the last 10 years. To support the activities described in the material, we made video recordings of music teachers and CI-users performing a range of activities. To ensure transferability to the target group, the material was read and commented on by seven experienced CI-teachers from other rehabilitation centers in Denmark.

**Results:** A web-based and a hardcopy of SCR's CI-music program has been developed with music activities related to pitch, timbre and rhythm including a thorough described guidance and video examples of how teachers can carry out the activities with the adult CI-users.

**Discussion:** The material is produced with focus on providing inspiration for how to conduct music teaching with adult CI-users and what activities to include. However, there is a risk that some teachers will still feel the lack of confidence conducting the teaching of music which may be outside of their primary subject area. A follow-up workshop for teachers might be needed.

**Conclusion:** Specialcenter Roskilde Kommunikation has developed an inspirational material for CI-teachers regarding rehabilitation of music enjoyment for adult CI-users. With this material we hope, that music teaching for the benefit of the CI-users will be more widespread on rehabilitation centers in Denmark.

**With special thanks to:**
Stine Kjær, Jeremy Marozeau, our colleagues from Specialcenter Roskilde and CI-network in Denmark, Kirsten Worsøe and the brave participating CI-users.

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**Title:** Auditory training program for music perception for adult cochlear implant users

**Authors:** **Charlotte Thostrup, Ditte Søbæk Johansen, Kirsten Worsøe and Mathilde Lumbye Orry**

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**Introduction:** The evolution of cochlear implants (CI) has led to advances in music perception in CI users. While there are limitations to the perception of music among CI users (Limb & Rubinstein, 2012), they nonetheless rank music as an important in their lives, right next to understanding speech (Gfeller et al., 2000) and show improved performance as a result of musical experience.

An auditory training program for music perception has therefore been added to the existing rehabilitation program for CI users. The objective of this study is to investigate whether an auditory training program for music perception for adult CI users results in an improved ability to experience music and enhances the enjoyment of music. The study also investigates whether the perception of speech among CI users can be improved as a result of auditory training of music perception.

**Methods:** Fifteen postlingually deafened adult CI users participated in this study. Aged 43 to 79 years old (average = 52,3 years). Before getting cochlear implants the participants had been unable to listen to and thus benefit from music for a period ranging from 10 to 40 years. The CI users were divided into two groups and each group received 14 hours of auditory training for music perception in group sessions over a 7-month period. Participants also trained individually at home in this time frame. The training was provided by a speech and hearing therapist and a music teacher. Auditory training was primarily performed with acoustic instruments and included listening to rhythmic music, playing on instruments and practicing pitch, rhythm, timbre and melody. The training also focused on understanding music and on music genres. The outcome of the training was monitored via a closed-set questionnaire method to assess music experience, music comprehension, the enjoyment of listening to music, and speech perception. During musical training video recordings were collected.

**Results:** Does systematic music training improve the ability to experience and enjoy music among CI users?
10 of 15 CI users report that they listen to music at home daily since the 7- month training period. 10 of 15 CI users report that they enjoy listening to music since participating in the 7-month training period. 9 of 15 CI users report that they listen to music in other settings than at home and talk about music with other people since participating in the 7-month training period. Do CI users experience progress in their perception of speech as a result of systematic musical training? After training 9 of 15 CI users report that their speech perception has improved since the 7-month training period.

**Results & Discussion:** The results show that most participants in the study experience positive effects regarding their ability to experience and enjoy music and their speech perception. However some of the CI users do not experience this progression. Participants in the study who had suffered from hearing loss the longest and those with only one CI showed the least progress. These factors may very well have contributed to a poor outcome of the musical training program for those individuals. Finally, it is possible that results would have been different if the subjective evaluation form was more sensitive. It is arguable that learning potential, motivation and expectations to the musical training and musicality also played a role in shaping results

Previous studies have shown that the ability to perceive speech correlates with the ability to perceive music in CI users (Won et al., 2010). It is possible that musical training can provide broader clinical benefit. Some of the participants in the study reported a greater awareness of speech sounds since participating in the auditory training program for music perception and that their spouses have noticed that they are paying more attention to speech.

**Conclusions and future research:** The results of this study suggest that most adult CI users can benefit from systematic musical training to improve their ability to experience and enjoy music, and enhance speech perception. These findings are limited due to the small sample size and the large individual differences.
For future evaluations, standardized objective evaluation tools, e.g. the Danish Hearing In Noise Test (HINT), should be included as a supplement to self-evaluation before and after music training. A reliable and valid translation of a clinical test for example the Clinical Assesment of Music Perception (CAMP) into Danish is requested as well.

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**Title:** Does musical training confer differential advantages in binaural integration and interaction tasks? A comparative study on instrumentalists and vocalists

**Authors:** Kavassery Venkateswaran Nisha and Prashanth Prabhu

**Affiliations:** All India Institute of Speech and Hearing

**Background:** Musical leisure activities, including playing an instrument, listening to music, and creating music, require a host of skills. The matrices governing precision in instrumental and vocal musicians relate to their manual and acoustical control in music respectively. Vocal musicians practice more with the speech sounds whereas instrumental musicians focus more on non-verbal sounds (Kumar & Krishna, 2019). Based on these differences, it might be logical to hypothesize that the complexity of auditory processes (temporal, intensity, and spectral) involved in learning and perceiving vocal and instrumental music can be different. The current study aimed at exploring the differences in binaural integration and interaction between instrumental and vocal musicians.

**Methods:** The study was conducted on 56 adults of the age range 20 to 50 years of experience in Indian classical music (at least 3y). They were divided into two groups: Group I (instrumentalists, n= 26) and Group II (vocalists, n=30). The binaural integration (Dichotic syllable test -DST) and interaction (interaural time difference -ITD and level differences-ILD, virtual spatial identification VASI) tests were administered on all participants. While DST, ITD, and ILD were conducted using the psychoacoustic toolbox in MATLAB version 2019b software, the VASI test was administered using Paradigm Player. The data obtained were tabulated and analyzed using IBM SPSS v26.

**Results:** A MANOVA revealed that instrumentalists had a significant advantage in binaural interaction tests including ITD, ILD, and VASI while the vocalists performed significantly better than instrumentalists in binaural integration task. The differential musical advantage (binaural interaction better in Instrumentalists, while integration better in vocalists) in the binaural tests shown in the study can be attributed to differences in the neural underpinnings in these psychoacoustical tasks.

**Discussion and Conclusions:** While use of syllables in DCT is governed by phonetics and left-hemispheric function, which is amplified in vocalists (as their profession involves memorizing and singing lyrics of the song), the use of right hemisphere functions for processing non-verbal aspects of music is fine-tuned in instrumentalists, leading to differential outcomes in binaural tests. The study findings highlight music-induced advantages in differential fine-tuning of binaural skills in instrumentalists and vocalists. The findings of the study have widespread implications in the field of Musicology, Rehabilitative and Education Audiology, wherein the role of instrumental musical training paradigms in exuberating maturation effects or counteract aging effects can be explored in detail.

**Title:** Effects of the music training program for children with cochlear implants

**Authors:** **Busra Yilanli, Halide Kara, Kubra Aydin, Ahmet Atas, Zahra Polat and Ozgur Yigit**

**Affiliations:** USKUDAR UNIVERSITY, Turkey

**Objective:** Pitch perception is important for the perception of music. Music has benefits in language and social development in early childhood. With recent advances in technology, cochlear implant users' expectations have increased. Research from the past ten years shows that musical training benefits cochlear implant users. The purpose of this study was to assess whether deaf children who use cochlear implants benefit from musical training.

**Material and Method:** Participants of this study were 20 children CI users (ages 2 to 12). The average duration of implant use was 3.3 months, and the 19 children were using unilateral cochlear implant and one child was using bilateral cochlear implant. Also, they were using a variety of different implant brands. Training consisted of weekly 3-hr sessions over a 24-week period. Musical training (such as listen to music together, sing songs, play rhythm patterns) consisted of one hour of auditory training, two hours of group and individual music lessons. Measures of musical skills were obtained pre-training and post-training with the Test Battery of Cerrahpasa University Evaluation of Perception of Music in Children with Cochlear Implant Users. The Test Battery of Cerrahpasa University Evaluation of Perception of Music in Children with Cochlear Implant Users was used to measure eleven different aspects of music perception (voice discrimination, timbre discrimination, loudness discrimination, pitch discrimination, tone separation, recognition of musical instruments, musical memory, pattern perception, rhythm information, tempo information, and vocal skills).

**Result:** Musical training led to improvement in different areas including performance on timbre discrimination, loudness discrimination, pitch discrimination, tone separation, recognition of musical instruments, musical memory, pattern perception, rhythm information, tempo information, and vocal skills.

**Conclusion:** As a result, we assert that music training will lead to the improvement of the perception of music for users of cochlear implants. Musical training may also support auditory rehabilitation. This study concludes that incorporating musical training into auditory training will help children who use cochlear implants. Music training can lead to improvements in perception of music and emotional speech prosody, and thus may be an effective supplementary technique for supporting auditory rehabilitation following cochlear implantation.

**Title:** Preliminary study of the effects of piano training in children with hearing loss

**Authors:** **Amineh Koravand, Antoine Poliquin, Sandra Markovic, Gilles Comeau and Laurel Trainor**

**Affiliations:** University of Ottawa, Canada

**Purpose:** The main objective of present study was to explorer the effect of piano lessons on the Cortical Auditory Evoked Potentials (CAEP) in children with normal and abnormal auditory function.

**Method:** 4- to 9-year-old children with normal hearing (NH) and with hearing loss, HL (users of Cochlear Implant, CI, and/or Hearing aids, HAs) participated in the study. CAEP were recorded in a passive oddball paradigm with verbal and nonverbal stimuli and they were measured before and after six months of intensive piano training. Special method of Piano teaching has been developed for children with HL.

**Results:** Different pattern of results have been found for pitch discrimination and CAEP in children with CI and/or with HAs before and after six months of training. A longer latency trend has been observed in children with HL. N2 and Mismatch Negativity's amplitude (MMN) values were different between the groups of participants. Larger N2 amplitude was found only in NH after the musical training.

**Discussion/Conclusion:** The aural approach for teaching classical music to CIs suggests that they can learn to recognize musical patterns and contours and enjoy music. Moreover, parents and teachers reported that the opportunity to participate in and understand music trends improved participants' social skills and behaviour. CAEP's findings suggest that 6 months of musical training may enhance some responses of CAEPs, however, some responses such N2 deflection may go through longer maturational delays in children with hearing impairment.

**Title:** Guided audiometer exploration (GAME):

**Authors:** **Eleanor Harding[1,2], Robert Harris[1,2], Etienne Gaudrain[1,3], Barbara Tillmann[3], Christina Fuller1, Rolien Free[1], Bert Maat[1], Deniz Başkent[1]**

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Hearing loss at any age can substantially affect quality of life. Cochlear implants (CIs) can partially restore hearing by stimulating the auditory nerve electrically. Unfortunately, complex auditory signals, such as found in music or in cocktail- party situations, remain challenging for CI users, largely due to the degradation of information stemming from electrical stimulation. But, through rehabilitation, CI users manage to adapt to these degradations to different degrees. One possible approach to boost rehabilitation in CI users is improvisation-based musical training, such as the Guided Audiomotor Exploration (GAME). As opposed to traditional score-based learning, improvisation-based training promotes audiomotor integration by relying on procedural memory and learning that couple movements on an instrument to sound production. Audiomotor integration, in turn, has been shown to boost activation of the auditory cortex in conjunction with top-down effects. These plastic changes could lead to improved central auditory processing of the degraded input. The current randomized controlled trial will offer GAME to adult CI users. In a pilot study with three CI users, participants enjoyed learning piano, gained personal confidence, and (re)gained appreciation for music. We aim to expand these results, and pursue transfer of learning effects to music and speech perception in CI users.

**Title:** Games for music training for cochlear implants

**Authors:** **Marianna Vatti, William Blackney and Manuel Segovia Martinez**

**Affiliations:** Oticon Medical

Cochlear implants (CI) have been remarkably successful in restoring the ability to understand speech-in-quiet in profoundly deaf patients. However, due to a number of device limitations, music perception with CIs remains generally poor. There is emerging evidence that auditory training may improve music perception skills and music enjoyment. Training programs designed for adult CI users are typically not available outside of research protocols. Furthermore, training activities can be rather tedious or boring and many CI users fail to complete them. The intrinsic motivation, persistence and positive attitude required can be of an additional challenge to the CI users. Therefore, there is a need for a tool that is entertaining, engaging and can contribute to long-term improvement in music perception.

The goal of this study was to develop a prototype of an innovative music training application that allows users to train on different musical aspects (e.g. pitch, timbre, harmonicity etc.). The main idea was to turn music training into a game. For that we drew inspiration from the mechanics of video games to understand the relevant motivational factors for our target CI groups. Finding appropriate objectives, challenges and rewards will ensure engagement and prolonged use of the training application. As of now, the application consists of several games that are intuitive and can be played by all ages. The games were built in a 2D environment with the use of the Unity game engine. We run a User Experience study to evaluate part of the prototype on a group of normal hearing and CI users and the results are presented and discussed.

**Title:** Long-range systematic training of the melodic contour

**Authors:** **Krzysztof R. Szymański**

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**Introduction:** It is well-documented that cochlear implants (CI) increase the quality of life of deaf people regardless of age. The most important benefit of CI is improving speech understanding in everyday listening environments. Early implantation in prelingually deaf children facilitate the later development of speech perception skills and speech intelligibility. Despite the evident benefits of speech recognition, vocal communication and rhythm appreciation, many aspects of sounds are not fully appreciated, including pitch, timbre intonation, and recognition of different simultaneous sources. Although music appreciation is subjective, there are objective methods for testing some elements of music understanding. One of the proposed measures of melodic pitch perception by CI users is the recognition of randomly-selected simple melodic contours (Galvin et al. 2007). This article reports the effects of long-range training performed by the author on himself. The author received CI after 40 years of single-sided deafness. Probably because of this long duration of hearing impairment, rehabilitation was difficult, and the author decided to use a long-term, controlled training programme.

**Methods:** Resources for hearing at Keck School of Medicine of USC (courtesy of R.L. Goldsworthy) were used for performing melody contour tests. Nine melodic contours of piano were generated using MIDI sampling and synthesis. The results of activity were registered on the Team Hearing (TH) platform. Excel files with data were further analysed using Mathematica software. Other hearing tests were developed using open-source score writer MuseScore, and software to allow random selection of the melodic contours. In both cases, the spacing between successive notes in the contour varied between 1, 2, 3 or 4 semitones. A particular test consisted of 18 calls, with the spacing for a contour in each call randomly selected between 1 and 4. The tests have been performed systematically since 2017, usually once or twice a day, sometimes with a few days between tests. Simultaneously with these music tests, listening to audiobooks and quantitative checks of speech recognition by counting incorrectly recognized words were carried out.

**Results and discussion:** Hearing training by cochlear implant was performed using either an audio cable connecting the CI processor and the audio source or an audio induction loop, to avoid sound detection by normal hearing. First words were recognized over a period of 5 months following surgery. After 14 months, recognizing any melodic contour on the TH platform was still very difficult. Therefore, the author designed a simpler test, aiming at the recognition of pitch difference between only two sounds. After 15 months of training on the two-tone test, the author was able to recognize some of the melodic contours on the TH platform. After another 15 months of training, score rate for piano contour recognition on TH increased to 95%. However, musical understanding and appreciation remain inferior to that of normal hearing. Moreover, such a high score for a particular music test does not correspond to a similar recognition level of the melodic contours of instruments other than the piano. Tests using other instruments and a varying position of the contours on the pitch scale are in progress. Nevertheless, systematic tests for audiobook recognition show a systematic increase in speech recognition.

**Conclusions:** Achieving a high score in recognition of melodic contours at selected tests does not correspond to good pitch recognition. Nevertheless, the training helps to increase speech understanding. It is an open question as to whether a variety of instruments and a diversity of pitch levels during long-range melodic contour training result in better recognition of musical elements by cochlear implant hearing.

## Making Sense of Music:

Brain Mechanisms that underpin Music Listening

**Title:** Exploring déjà entendu: a comparative study between musicians and non-musicians

**Authors:** **Aashish Sharma, Tanvi Sanghavi and Prashanth Prabhu**

**Affiliations:** All India Institute of Speech and Hearing, India

**Background:** Music plays an important role in everybody's lives, regardless of the individual being a musician or not. The auditory sensation of déjà vu, déjà entendu, a lesser-known term that refers to the sensation of familiarity with sounds. The experience of familiarity of music without retrieval that is Recognition without identification (RWI) has been related to the sensation of déjà entendu.

The present study applied the RWI paradigm with familiar and unfamiliar songs and rhymes. Auditory recognition memory was also explored for both groups. The sensation is affected by a number of factors like how often a song was heard, how often an individual listens to a certain style of a song, attention to music and rhythm etc. Since musicians are able to grasp the finer aspects of songs and attend to songs more often, the hypothesis of this study was that the sensation of RWI should be lesser in this group. Thus, the present study aimed to compare the sensation of RWI between musicians and non-musicians.

**Method:** Thirty young adults were included in the study between age ranges of 18-30 years. The participants were grouped into two categories i.e musicians and non-musicians. The musicians had received formal training for more than five years and some of them spent dedicated time playing instruments.

Participants were instructed to listen carefully to the songs played and identify the songs. They were asked to say the name and style of the song. The examiners played the instrumental part of songs for a duration of five seconds. Examiners noted the accuracy and the reaction time of the responses. The responses were grouped into "Recognized and identified both name and style of song", "Recognized and identified only name of the song", Recognized and identified only style of the song", "Recognized but not identified", "Neither recognized nor identified".

**Results:** Independent samples t-tests were done to compare between the two groups. The results showed that the reaction time was significantly faster for musicians compared to non-musicians. As hypothesized, the RWI was significantly lesser in musicians compared to non-musicians. The results of paired samples t-test showed that there was no statistically significant difference between familiar and unfamiliar songs and rhymes in both the groups.

**Discussion/Conclusions:** The present study gives interesting insights. The feeling of familiarity and recognition are closely related. Recognition without identification is found to be more for non-musicians compared to musicians. Possible reasons for this finding could be due to better auditory processing, perception of rhythm, pitch, tempo and loudness by musicians compared to non-musicians. Thus, the task did not require musical abilities to perform better, rather enhanced attention and auditory working memory of musicians which resulted in improved performance.

**Title:** Does the quality of pre-implant hearing experience relate to post-implant music listening experience?

**Authors:** Cheuk Chee Cynthia Lam, Brian C. J. Moore and Deborah A. Vickers

**Affiliations:** University of Cambridge, UK

Cochlear implants (CIs) can partially restore hearing to individuals who suffer from severe-to-profound hearing loss (1). However, CIs have been primarily designed to facilitate speech perception, and there are other aspects of listening via CIs that need to be improved. One example is music perception. Music listening is a big part of human culture, and it is known to evoke many different emotions and activate brain circuits responsible for reward, pleasure and emotion. The majority of adult CI users report a reduction in music enjoyment and time spent listening to music post-implantation relative to before implantation at a time when their hearing was better (2). The most commonly reported problems are poor/abnormal sound quality and low clarity of music. Correlations have been found between enjoyment, sound quality and listening habits before and after implantation (3), as well as between the amount of time spent on music listening and enjoyment after implantation. However, the nature of pre-implant hearing experiences, such as age of onset of deafness, hearing levels, use of hearing aids and duration of deafness, could affect post-implant music enjoyment. The exploration of these factors forms the basis of the current study, which aims to explore the relationship between pre-implant hearing experiences and post-implant music perception, appreciation and enjoyment.

The Munich Music Questionnaire (MUMU) was selected for this online study to measure the role of music in participants' lives. It includes questions on music listening behaviour, appreciation, perception, experience and education. An online fundamental frequency discrimination task using simulated piano chords (4) is being used to assess pitch perception after implantation. Twenty-five participants (Thirteen females and Twelve males) completed the questionnaire, and twenty-three of them completed the pitch discrimination task, aged 29-86 years. Participants from the pitch task were split into prelingual group (n=11) and postlingual group (n=13) for analyses. Exploratory factor analysis revealed three demographic factors that influenced music listening: duration of hearing difficulty, age aspects (which include demographic data in the age of onset and age of implantation) and years of CI listening. Three hearing-related factors emerged from the MUMU: hearing quality from the CI, music education and music listening habits. The relationship between demographic factors, hearing experience factors and post-implant pitch perception will be explored. We will also compare music listening habits between pre- and post-lingual CI users to understand the impact of having pre-lingual hearing loss on experiences when listening to music. In the future the results from this study will be compared to EEG responses to complex tones and music to uncover the underlying relationship between hearing experience and music perception for CI users.

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**Title:** Music in the mind

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**Affiliations:** Guys' and St Thomas Auditory Hearing Implant Centre, London

**Background:** A significant proportion of the Adult cochlear implanted caseload (50.5%) includes adults who are elderly and/or have medical comorbidities. Increasingly, they are vulnerable adults with hearing health and communication impacted by cognitive decline, including dementia; potentially creating a barrier to accessing clinic-based services. Currently, there are no rehabilitation resources, specifically designed for this increasing ageing adult population, which integrate with the technology for pre- & post-implementation.

A growing body of research highlights the positive impact of regular music activities in improving quality of life and enhancing domain general cognitive functions for elderly adults with cognitive decline and dementia. Music engagement has been correlated with improvement in some areas of executive function. Positive outcomes have been evidenced through singing; additionally improving caregiver wellbeing (Bugos et al., 2007; Hanna-Pladdy & MacKay, 2011; Kattenstroth et al., 2010; Mammarella et al., 2007; Parbery-Clark et al., 2011;Foster & Valentine, 2001; Irish et al., 2006; Mammarella et al., 2007; Sluming et al., 2002, Schellenberg, 2011).

The rehabilitative use of music, sound and voice within a multi-sensory approach has not been systematically explored in implanted elderly adults with levels of cognitive decline and dementia. Our aim is to determine the efficacy of a novel rehabilitation intervention based on coaching the caregiver and adult in adopting communication strategies, optimum use of technology and a unique multi-sensory, music, sound and voice rehabilitation resource which can be used regularly as a part of everyday care.

**Method:** Phase One
- Prototype design and content development
- Research period assessing the efficacy of the practical elements
- 15 individual rehabilitation sessions with caregivers and adults with cochlear implants, cognitive decline and dementia

**Method:** Phase Two
- 16 caregiver dyads will be randomised to a 6 week music, multi-sensory and communicative strategies rehabilitation group (n = 8), or a usual care control group (n = 8)
- All participants will complete pre- and post-measures, including the GAST quality of life, STEC scales and digit symbol coding
- Outcome measures will be repeated after 6 months

**Results:** Phase One
- Prototype materials have been developed
- Due to COVID-19, virtual individual trailing sessions are in process
- Adaption of the materials based on outcomes have been implemented for remote and face-to-face delivery of the intervention
- Outcomes from these sessions have indicated the materials are engaging, motivating, flexible in delivery and adaptable to the needs of individual adults with differing cognitive levels

**Title:** MMN as a reliable marker of music discrimination in individual cochlear implant users

**Authors:** **Bjørn Petersen[1], Niels Trusbak Haumann[1], Anne Sofie Friis Andersen[1], Kathleen F Faulkner[2], Elvira Brattico[1], Peter Vuust[1]**

**Affiliations:** Center for Music in the Brain, Department of Clinical Medicine, Aarhus University and The Royal Academy of Music, Aarhus/Aalborg, Denmark[1], Oticon Medical, Smørum, Denmark[2]

**Background:** Cochlear implant (CI) users' enjoyment of music and understanding of spoken language depends not only on hearing sounds but also on distinguishing between them. While sound sensation is typically measured from the auditory brainstem response, no common objective measure has been established for testing sound discrimination ability. We here propose the cortical mismatch negativity response (MMN) and spike density component analysis (SCA) as novel diagnostical tools.

**Methods:** 11 experienced CI users and 14 normal hearing controls listened to the CI MuMufe MMN paradigm. MMN responses to deviant tones for 4 sound features each tested at 4 magnitude levels were measured with electroencephalography (EEG). The individual MMN was automatically detected with SCA statistics. Attentive sound discrimination ability was measured with a behavioral test.

**Results:** Automatically detected individual MMN responses predicted CI users' behavioral sound discrimination ability with high (~90%) accuracy, even for complex music stimuli. SCA statistics, tailored for analysis on individuals, showed significantly higher diagnostic accuracy ($p < .001$) and reliability (replication across individuals ($p = .003$) than previous methods inspired by group level EEG analysis.

**Conclusion:** In conclusion, the individual MMN correctly predicted auditory discriminative ability in approximately 9/10 cases, which suggests that the individual MMN can be applied as a reliable diagnostic marker for assessing music discrimination in CI users.

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**Title:** Adapting to the sound of music - development of music discrimination skills in recently implanted cochlear implant users

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**Background:** Cochlear Implants (CIs) are optimized for speech perception but poor in conveying music, especially pitch, melody and timbre. Here, we investigated early development of discrimination of music in recently implanted CI users (CIre).

**Methods:** The CIre group was tested twice, 1) shortly after activation of the implant (T1) and 2) approximately 3 months later (T2), using an MMN-paradigm and a behavioral test. For reference, a group of experienced CI users (CIex) and a group of normally hearing (NH) controls were tested once. Four different deviant features (intensity, pitch, timbre and rhythm) at four levels of magnitude (small, medium, large and extra-large) were presented in both tests, adding to a total of 16 variants.

**Results:** While no significant MMN responses were found at T1, CIre showed significant MMN responses for the timbre and pitch deviants at T2. This reflected a significant progress in the neural discrimination of these particular deviants. In their behavioral discrimination, CIre scored above chance level at both times of testing for all features, but significantly below the NH reference for all features except rhythm. Both CI groups scored significantly below NH in discrimination of pitch. The CIre group's behavioral discrimination showed no significant progress, suggesting that the early development is more clearly reflected neurophysiologically. Qualitative data showed a significant progress in the CIre group's rating of the quality of the sound of music.

**Conclusion:** Cochlear implant users show early adaptation to spectral features of music neutrally, but not behaviorally, after just three months of experience.

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We share the belief that multi-disciplinary research across the various fields of hearing care builds the path to improved music perception.

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