Emotions and Psychological Mechanisms of Listening to Music in Cochlear Implant Recipients

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Objectives: Music is a multidimensional phenomenon and is classified by its arousal properties, emotional quality, and structural characteristics. Although structural features of music (i.e., pitch, timbre, and tempo) and music emotion recognition in cochlear implant (CI) recipients are popular research topics, music-evoked emotions, and related psychological mechanisms that reflect both the individual and social context of music are largely ignored. Understanding the music-evoked emotions (the "what") and related mechanisms (the "why") can help professionals and CI recipients better comprehend the impact of music on CI recipients' daily lives. Therefore, the purpose of this study is to evaluate these aspects in CI recipients and compare their findings to those of normal hearing (NH) controls.

Design: This study included 50 CI recipients with diverse auditory experiences who were prelingually deafened (deafened at or before 6 years of age)—early implanted (N = 21), prelingually deafened—late implanted (implanted at or after 12 years of age—N = 13), and postlingually deafened (N = 16) as well as 50 age-matched NH controls. All participants completed the same survey, which included 28 emotions and 10 mechanisms (Brainstem reflex, Rhythmic entrainment, Evaluative Conditioning, Contagion, Visual imagery, Episodic memory, Musical expectancy, Aesthetic judgment, Cognitive appraisal, and Lyrics). Data were presented in detail for CI groups and compared between CI groups and between CI and NH groups.

Results: The principal component analysis showed five emotion factors that are explained by 63.4% of the total variance, including anxiety and anger, happiness and pride, sadness and pain, sympathy and tenderness, and serenity and satisfaction in the CI group. Positive emotions such as happiness, tranquility, love, joy, and trust ranked as most often experienced in all groups, whereas negative and complex emotions such as guilt, fear, anger, and anxiety ranked lowest. The CI group ranked lyrics and rhythmic entrainment highest in the emotion mechanism, and there was a statistically significant group difference in the episodic memory mechanism, in which the prelingually deafened, early implanted group scored the lowest.

Conclusion: Our findings indicate that music can evoke similar emotions in CI recipients with diverse auditory experiences as it does in NH individuals. However, prelingually deafened and early implanted individuals lack autobiographical memories associated with music, which affects the feelings evoked by music. In addition, the preference for rhythmic entrainment and lyrics as mechanisms of music-elicited emotions suggests that rehabilitation programs should pay particular attention to these cues.

Key words: Cochlear implants, Emotion mechanisms, Music-evoked emotions, Music perception.

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INTRODUCTION

Cochlear Implants and Music

Understanding and anticipating the advantages and disadvantages of cochlear implant (CI) technology, with a particular focus on the experiences of CI recipients, is a complicated and diverse subject. In recent decades, it has been demonstrated that CI technology has produced exceptional benefits in speech perception for adults (Boisvert et al. 2020) and children (Sharma et al. 2020) with a variety of hearing problems, including bilateral deafness, unilateral deafness, residual acoustic hearing, and auditory neuropathy (Naples & Ruckenstein 2020). On the other hand, music perception remains challenging for patients using CI due to the complexity of music and the processing limits of current CI technology. Most research on this subject has been on the technological limitations of CI and its impact on the fundamental psychoacoustics of music, with an emphasis on pitch, timbre, rhythm, and melody perception [see reviews by Oxenham (2008), Limb and Rubinstein (2012), Limb and Roy (2014), and, Jiam and Limb (2020)]. CI recipients perform significantly poorer than normal hearing (NH) listeners in almost each of these aspects, and various methods were proposed to improve music perception. One strategy is the development of a novel CI signal processing strategy that transforms the harmonics of a musical source into modulators conveying the amplitude and temporal fine structure cues to the CI electrodes (Li et al. 2013) or into vibrotactile-haptic perception (Luo & Hayes 2019; Fletcher et al. 2020; Huang et al. 2020). Remixing or preprocessing of music has also been proposed (Buyens et al. 2014; Pons et al. 2016; Gajęcki & Nogueira, 2018; Tahmasebi et al. 2020). All these studies provide valuable data for the assessment of music perception and propose new and exciting opportunities for the CI community. However, music involves higher-order processes than mere sensory stimulation, and attention should be paid to other aspects of music such as music-evoked emotions and music appraisal.

Emotions and Music

Subjective appraisal is a fundamental aspect of music, with two dimensions requiring initial consideration in CI recipients. First, individuals who received CI had significantly lower music appraisal ratings than before their hearing loss (Gfeller et al. 2000; Mirza et al. 2003) and NH listeners (Gfeller et al. 1998, 2002). Second, the predictive power of music perception skills in CI recipients for their appraisal ratings is often inadequate or nonexistent (Wright & Uchanski 2012; Drennan et al. 2015). This "disconnect" between musical enjoyment and measures of music perception skills in CI recipients is to be expected given that music in everyday life possesses psychoacoustic (Won et al. 2010; Jung et al. 2012; Yüksel & Çiprut 2020), cognitive (Gfeller et al. 2008; Schellenberg & Weiss 2013), cultural (Cross 2001; Bennett 2002), aesthetic (Juslin et al. 2016), and

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most importantly, emotional (Juslin 2013) aspects. Among these dimensions of music, emotion demands special consideration, given that music has strong historical, psychological, and neurophysiological connections with emotions (Juslin & Sloboda 2013).

Emotion in music has been a fascinating topic for millennia, starting with the ancient Greeks (Budd 2002). Emotional expression in music is a significant aspect of its aesthetic value (Juslin 2013). It has been demonstrated that music can conduct (Balkwill & Thompson 1999) and induce (Juslin & Laukka 2004) emotions, and, in turn, music enjoyment can also be influenced by various emotional states (Brattico et al. 2009; Garrido & Schubert 2011; Brattico 2015). Emotions are governed by neurobiological mechanisms and are influenced by sociocultural factors (Mesquita 2009). They serve as mediators between external events and the dynamic responses in the individual. Koelsch (2020) conducted a meta-analysis of 47 neuroimaging studies on music-evoked emotions in 994 NH participants. They found several neural structures related to music-evoked emotions, including the amygdala, anterior hippocampus, auditory cortex, and structures of the reward network, such as the ventral and dorsal striatum, anterior cingulate cortex, orbitofrontal cortex, and secondary somatosensory cortex. These findings support the idea that music is a highly gratifying experience for the human brain, which should be viewed in light of the relationship between emotions and the brain's reward system (Sander & Nummenmaa 2021).

Emotions, Music, and CIs

Despite the strong and prominent relationship between music and emotions, few studies (Brockmeier et al. 2011; Hopyan et al. 2011; Rosslau et al. 2012; Volkova et al. 2013; Ambert-Dahan et al. 2015; Caldwell et al. 2015; Giannantonio et al. 2015; Hopyan et al. 2016; Shirvani et al. 2016; Paquette et al. 2018; Luo & Warner 2020) have focused on musical emotion recognition and/or rating tasks in CI patients. These studies used similar approaches to evaluating musical emotion recognition or identification and employed brief tasks which aimed to pair specific emotions (e.g., happy, sad, angry) with a specific musical excerpt. The data demonstrated that CI recipients perform worse on musical emotion recognition tasks due to poor ability to discriminate major and minor modes than their NH peers (Brockmeier et al. 2011; Hopyan et al. 2011, 2016) and that music-focused programming of the CI sound processor (Rosslau et al. 2012), bilateral and/or bimodal hearing (Volkova et al. 2013; Shirvani et al. 2016), and additional timbre cues (Paquette et al. 2018; Luo & Warner 2020) may improve musical emotion recognition. Additionally, experience can influence the recognition of musical emotions, particularly in younger CI recipients with acoustic hearing (Giannantonio et al. 2015). These studies provide remarkable evidence on the psychoacoustical aspects of music and, in almost every case, demonstrated that CI recipients have limited emotional recognition of music.

However, these studies do not adequately reflect the effect of music-evoked emotions on the daily lives of CI recipients. Contrary to musical emotion recognition paradigms, which are momentary in nature, music-evoked emotions reflect a more general and subjective perspective on the music–emotion relationship, focusing on self-reported measures of how music makes listeners "feel" and which variables contributed to this process.

Even though musical emotion processing is highly subjective and variable on both the individual and cultural levels (Juslin & Sloboda 2013), positive emotions (e.g., happiness, joy, relaxation, and enjoyment) usually rank first as the most often experienced emotions and comprise the upper 20% of emotions expressed. However, negative emotions (e.g., sadness, pain, anger, and despair) do not score consistently throughout studies conducted in different cultures (Kreutz 2000; Lindström et al. 2003; Juslin & Laukka 2004; Saarikallio et al. 2021). Considering the impact of emotions in music, these observations suggest that music-evoked emotions should be assessed in detail to understand the subjective emotional experiences and relevant impact of music in the daily lives of listeners.

Psychological Mechanisms of Music Listening

Factors contributing to music-evoked emotions are related to "how" these emotions are evoked, that is, the mechanisms involved in the processes that link emotions and music. Although various mechanisms have been proposed in the literature, a comprehensive framework has been proposed by Patrick N. Juslin (Juslin & Västfjäll 2008; Juslin 2013). Juslin et al. (2016) provided a summary of the nine mechanisms that comprise the BRECVEMAC framework, which involves the following simple reflexes to complex cognitive processes:

1. Brainstem reflex: response to simple and fundamental acoustic features such as sudden loudness or pitch changes.
2. Rhythmic entrainment: adjustment of internal body rhythm to an external musical rhythm.
3. Evaluative conditioning: conditioned associations of a musical piece with other stimuli.
4. Contagion: an internal mimicry of the emotional expression modeled on a perceived voice in the music.
5. Visual imagery: inner images connected with the metaphorical mapping of the musical structure.
6. Episodic memory: trigger of memories of a particular event by a musical pattern.
7. Musical expectancy: expectations regarding the compositional structure of the continuation of music.
8. Aesthetic judgment: a personal judgment regarding the aesthetic value of music.
9. Cognitive evaluation: relationship of music with the listener's current goals or plans in life.

The authors developed this framework based on the previous literature that reported the prevalence estimates of these constructs. Previous studies showed that this mechanistic framework provides a comprehensive perspective on music-evoked emotions and preferences, with expected variations at the cultural/country and subjective/personal levels (Juslin & Västfjäll 2008; Juslin 2013; Juslin et al. 2016; Koelsch 2020; Saarikallio et al. 2021; Barradas & Sakka 2022).

Music-Evoked Emotions and Aural Rehabilitation in CI Recipients

The influence of music-evoked emotions on CI recipients is critical in both theoretical and practical considerations. The neural connections fostered by emotions between music and other developmental domains facilitate the use of music as a rehabilitative intervention that can assist the development of hearing, speech, and language (Kraus & Chandrasekaran 2010; Tierney & Kraus 2013; Sihvonen et al. 2017). Even though there is an ongoing discussion (see review by McKay 2021), there is substantial literature on the benefits of music as a rehabilitative tool (Gfeller 2001; Chen et al. 2010; van Besouw et al. 2014; Good et al. 2017), which provides a reliable basis for such interventions. However, music-evoked emotions have often been overlooked in CI recipients. Emotions serve as an adaptive tool that can modify behavior for the survival or the well-being of organisms (Keltner & Gross 1999). Thus, their impacts should be considered in any type of music-related behavior-modifying interventions, including music training, and music-based aural rehabilitation for CI recipients.

Therefore, this study aims to provide fundamental data for music-evoked emotions in CI recipients by (a) evaluating music-evoked emotions and the relevant mechanism using the BRECVEMAC framework in CI recipients, (b) comparing the findings with NH controls, and (c) evaluating the effects of different auditory exposure and experiences between prelingually and postlingually deafened CI recipients on music-evoked emotions.

MATERIALS AND METHODS

Participants

A total of 100 individuals participated in the study, including 50 CI recipients (mean = 27.6 years, range = 18–70 years, standard deviation = 14.4 years, 40 females) and 50 controls with NH (mean = 24.4 years, range = 18–48 years, standard deviation = 7.8 years, 38 females).

This study included all CI recipients who were willing to participate and meet the inclusion criteria during their regular fitting appointments for a period of 6 months. Inclusion criteria were more than one year of CI use, age above 18 at the time of assessment, and proven normal anatomy of the eighth and cochlear nerves via radiological evaluation. After data collection, CI participants were primarily categorized as prelingually deafened during 0 to 6 years of age: early implanted (PreD-EI; N = 21), prelingually deafened: late implanted (implanted after 12 years of age – PreD-LI; N = 13), and post-lingually deafened (PostD; N = 16).

The inclusion of PreD-LI participants was based on recent observations that PreD-LI CI recipients exhibited remarkably superior music perception compared to PreD-EI (Fuller et al. 2013, 2019). Moreover, compared to PreD-EI CI recipients, less is known about music perception and emotions in PreD-LI CI recipients. The PreD-LI inclusion criteria required at least a 5-year gap between the diagnosis of hearing loss and the age of implantation to ensure a period of significant auditory deprivation. The average age of hearing loss diagnosis and implantation was 39 months and 21.8 years of age, respectively, and the age difference between hearing loss diagnosis and implantation ranged from 7 to 32 years, with an average of 18.5 years. in the PreD-LI group. We believe this would provide more comprehensive data on various subpopulations of CI recipients and crucial information for implantation decisions involving these groups. In addition, considering the high number of bimodal users (N = 22; unilateral CI recipients with a hearing aid in the contralateral ear), we also presented the data obtained from bimodal users.

All participants in PreD-LI and PostD groups were regular hearing aid users whose follow-up was conducted in the same university clinic before CI. The basis for their selection as candidates for CI was the presence of auditory and speech-language development, as required by legislation, which indicates a maximum of 4 years of difference between chronological and receptive and/or expressive language development ages or having a receptive and/or expressive language age of 4 years or more. After utilizing CI, all participants communicated orally and had some degree of speech perception (speech and/or CVC word recognition scores). Age upon diagnosis, CI use, CVC word recognition scores, and hearing thresholds for four frequencies was also recorded. Word recognition scores and hearing thresholds were measured in best-aided conditions (i.e., free field testing with CI in all participants and with a contralateral hearing aid in bimodal users). Tables 1–3 provide further information about the CI group.

Inclusion criteria for NH participants included a minimum age of 18 and the absence of any hearing abnormalities or cognitive issues that could affect study participation. All participants were informed of the study at the outset of the survey, and approval from the university's ethics board (No: 96, March 21, 2022) was obtained before the study.

Procedures

This study had a survey research design. Initially, a list of 72 emotion terms was selected based on comparable international (Kreutz 2000; Lindström et al. 2003; Juslin & Laukka 2004; Zentner et al. 2008; Saarikallio et al. 2021) and language-culture-specific studies by Er (2006) and Yakup and İlhan (2021). Words were ranked for their prevalence in the language using a national corpus (Aksan et al. 2012). Words in the lowest 50% were removed, resulting in 36 words remaining in the final list.

NH participants were invited to participate in this study via the university noticeboards and several online forums and asked to complete an online questionnaire. Before filling out the questionnaire, all participants were invited to reflect on music or songs that were meaningful to them and to complete a questionnaire regarding their emotions in this regard. Participants in the CI group completed the questionnaire under the guidance of the second author of this study. Participants in the PostD CI group were asked to focus on their experiences with the CI, not before their hearing loss, while bimodal users in the CI group were asked to focus on their daily device usage (i.e., not only with CI). As previously stated, this method differs from the momentary music-evoked emotions elicited by a specific musical stimulus. Instead, this method encourages participants to reflect on inner experiences, personal meaning, and the emotional influence of music outside of a research environment.

The survey contained seven questions in total. After two questions regarding age and gender, the following questions were asked: "On average, how many hours per week do you listen to music?" and "Have you received formal musical training that lasted longer than a year?" to obtain a basic understanding of their formal musical training and music listening habits. Next, participants were asked, "Approximately, how much of the total time you listen to music do you experience emotions?" Responses were scored on a percentage scale ranging from 0% to 100%, and this was termed the "emotion feeling percentage" (EFP). The purpose of this was to determine the frequency of emotion induction while listening to music. The next two questions (Appendix 1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/B168) were 5-point Likert scales

TABLE 1. Participant details of cochlear implant recipients

CI Condition	Age	HL Age (mo)	CI Age (y)	DC	CI Processor	CI Electrode
Prelingual—early implanted	20	18	4	Unilateral	Rondo 3	Sonata
	18	24	7	Bimodal	Nucleus 7	CI24RE
	22	24	2.5	Unilateral	Nucleus 6	CI24R
	28	15	7	Unilateral	Nucleus 7	CI24M
	19	24	6	Unilateral	Nucleus 7	CI24RE
	18	12	5	Unilateral	Kanso	CI24RE
	18	30	8	Bimodal	Nucleus 6	CI24RE
	18	6	5	Bimodal	Sonnet 2	Sonata
	18	9	7	Bimodal	Sonnet 2	Sonata
	18	36	4	Bimodal	Kanso 1	CI24RE
	18	30	8	Bimodal	Nucleus 6	CI24RE
	18	15	4	Bimodal	Kanso 1	CI24RE
	18	8	3	Bilateral	Nucleus 6	CI24RE
	24	48	5	Unilateral	Nucleus 6	CI24RE
	23	12	4	Unilateral	Nucleus 7	CI24RE
	20	2	4	Unilateral	Nucleus 6	CI24RE
	18	24	7	Unilateral	Nucleus 6	CI24RE
	20	24	5	Unilateral	Nucleus 6	CI24RE
	20	36	5	Unilateral	Nucleus 6	CI24RE
	18	60	3.5	Unilateral	Kanso 2	CI24RE
	18	15	3.5	Unilateral	Nucleus 5	CI24RE
Mean (N = 21)	21.0	22.5	5.1			
Prelingual—late implanted	33	12	31	Unilateral	Kanso 1	CI24RE
	18	84	14	Bimodal	Kanso 1	CI422
	24	60	23	Bimodal	Rondo 3	Sonata
	21	48	20	Bimodal	Kanso 1	CI24RE
	19	24	16	Unilateral	Kanso 1	CI24RE
	22	15	20	Unilateral	Kanso 1	CI24RE
	37	24	34	Unilateral	Nucleus 6	CI24RE
	24	48	19	Unilateral	Nucleus 6	CI24RE
	30	48	29	Bimodal	Kanso 1	CI24RE
	20	24	19	Bimodal	Nucleus 6	CI24RE
	20	24	19	Bimodal	Nucleus 6	CI24RE
	28	24	25	Bimodal	Kanso 1	CI24RE
	18	72	14	Bimodal	Kanso 1	CI422
Mean (N = 13)	24.2	39.0	21.8			
Postlingual	42	420	41	Unilateral	Nucleus 6	CI24RE
	37	156	14	Unilateral	Kanso 1	CI24M
	59	300	36	Unilateral	Nucleus 7	CI24M
	18	96	16	Bimodal	Kanso 1	CI422
	56	456	55	Bimodal	Rondo 2	Sonata
	70	756	62	Bimodal	Saphyr	Unknown
	18	108	12	Unilateral	Nucleus 5	CI24RE
	29	96	9	Unilateral	Kanso 2	CI24RE
	63	600	62	Unilateral	Kanso 1	CI24RE
	47	420	46	Unilateral	Nucleus 6	CI422
	20	144	12	Unilateral	Sonnet	Sonata
	52	72	32	Unilateral	Nucleus 6	CI24RE
	21	108	21	Bimodal	Rondo	Sonata
	18	84	18	Bimodal	Rondo	Sonata
	40	84	35	Bimodal	Kanso 1	CI24RE
	66	360	61	Bimodal	Nucleus 6	CI24RE
Mean (N = 16)	41.0	266.3	33.3			
Mean	28.24	104.78	18.43			

CI, cochlear implant; DC, device condition; HL, hearing loss.

ranging from "never," "rarely," "occasionally," "frequently," and "always." The first question asked, "Please estimate the frequency with which you experience each of the following emotions in reaction to music," and enumerated the 36 emotions.

The final question was "Please estimate how frequently your emotional responses to music are attributable to each of the following causes," and participants answered ten items that were developed to reflect the nine components in the BRECVEMAC framework and the lyrics (Juslin et al. 2016). Items from the BRECVEMAC framework that were included in the questionnaire were as follows: "Sudden—startling events (e.g., very loud sound, sudden tonal changes) in music" for brainstem reflex, "Strong and captivating rhythms in music" for rhythmic entrainment, "Moments that evoke memories and past events" for evaluative conditioning, "Associations that arouse emotions" for contagion, "Visual stimulations and images evoked by music" for visual imagery, "The emotional expressions in music evoke touching moments" for episodic memory, "Unexpected or inventive changes in music" for musical expectancy, "Aesthetically valuable (e.g., beautiful, original) pieces of music" for aesthetic judgment, "Practical consequences for my goals or plans in life" for cognitive evaluation, and "Lyrics in music" for lyrics. The final question was added to incorporate the known effects of lyrics on music-evoked emotions (Barradas & Sakka 2022) and to allow comparison of our data with similar studies, such as Juslin et al. (2016).

Data analysis

Descriptive statistics of the survey results and participant ratings are presented in tabular and graphical forms. We transformed the Likert scale ratings of emotions and mechanisms to numbers between 1 and 5 for analysis. A preliminary analysis was conducted to decide which emotional words should be included in the final analysis. The emotions that ranked in the bottom 20% of mean scores were removed to ensure that factor analysis included the emotions that were truly relevant to the musical experiences of the participants. These emotions were humiliation, disgust, surprise, jealousy, shame, humor, agitation, and affectation. For the experimental group (CI), the emotion ratings were subjected to a principal component analysis (PCA) to minimize dimensionality, with 28 emotions included in the PCA.

Due to the ordinal nature of the Likert scale assessments, the Mann–Whitney U test was utilized to compare CI with NH groups and bimodal with unilateral CI users. The Kruskal–Wallis H test was employed to compare the three CI groups. Additionally, correlation analysis was performed to determine the association between questionnaire scores and the demographic variables of chronological age, hearing loss diagnosis age, and cochlear implantation age. Bonferroni correction (alpha/number of tests) was implemented due to the high number of tests comparing emotion scores (N = 28) to reduce the likelihood of Type 1 errors. Consequently, $p < 0.05$ was utilized in all statistical tests except for emotion ratings, for which $p < 0.002$ was considered significant.

RESULTS

Weekly music listening hours, EFP, word recognition scores, and PTA (pure-tore threshold average; 500, 1000, 2000, 4000 Hz under the best-aided condition) values of CI groups and NH groups are presented in Tables 2 and 3.

TABLE 3. Music listening data and demographics of bimodal CI recipients

	Bimodal Users (N = 22)	
	Mean	SD
Weekly listening (h)	5.65	2.38
Emotions moments (%)	76.25	5.09
Music training (yes, N)	3.00	
WRS (%)	56.93	7.71
PTA (dB HL)	27.62	1.19

CI, cochlear implant; NH, normal hearing; PTA, pure-tone average; WRS, word recognition score.

Emotion Ratings and PCA

The emotional scores for the CI and NH groups are reported in Figure 1. In the CI group, happiness, joy, love, interest, trust, hope, and pride were in the highest 20%, while disappointment, tenderness, regret, anxiety, anger, fear, and guilt were in the lowest 20% of the emotion ratings.

The PCA was conducted for the CI group, and the suitability of PCA was first assessed before analysis. Inspection of the correlation matrix showed that all emotions had at least one correlation coefficient greater than 0.3. Nostalgia, excitement, and confidence were removed from the final analysis due to unacceptably low individual Kaiser-Meyer-Olkin (KMO) scores of 0.259, 0.423, and 0.425, respectively. According to Kaiser (1974), variables with scores below 0.5 are problematic for factory analysis and should be excluded. The overall KMO measure was 0.65, and all individual KMO measures were more than 0.6, denoting "mediocre" to "middling" performance. Bartlett's sphericity test results were statistically significant ($p < 0.001$), indicating that the data were likely factorizable.

Five components with eigenvalues greater than 1 were revealed by PCA. These explained 28.05%, 15.17%, 7.36%, 6.72%, and 6.12%, respectively, of the total variance. In addition, a five-component solution satisfied the criteria for interpretability. Therefore, five components were retained.

The five-component solution explained 63.4% of the total variance. A Varimax orthogonal rotation was employed to aid interpretability. The rotated solution exhibited a "simple structure" (Thurstone 1947). The factor loadings for five factors with Varimax rotation with Kaiser normalization are presented in Table 4. Emotions with moderate loadings (>0.50) for their respective factors are shown in bold.

TABLE 2. Music listening data and demographics of CI recipients and NH participants

	CI Recipients								NH Participants (N = 50)	
	Total (N = 50)		PreD-EI (N = 21)		PreD-LI (N = 13)		PostD (N = 16)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weekly listening (h)	5.86	1.06	7.37	2.17	6.38	2.94	3.91	0.79	13.63	1.46
Emotions moments (%)	70.40	3.42	73.12	5.82	77.69	6.52	59.10	8.14	66.31	2.68
Music training (yes. N)	5		2		3		0		4	
WRS (%)	62.12	6.93	76.25	2.69	43.31	8.03	48.36	9.21		
PTA (dB HL)	27.89	2.13	28.19	2.81	27.62	1.02	27.73	1.71		

CI, cochlear implant; NH, normal hearing; PreDEI, prelingually deafened, early implanted; PreDLI, prelingually deafened, late implanted; PostD, postlingually deafened; PTA, pure-tone average; WRS, word recognition score.

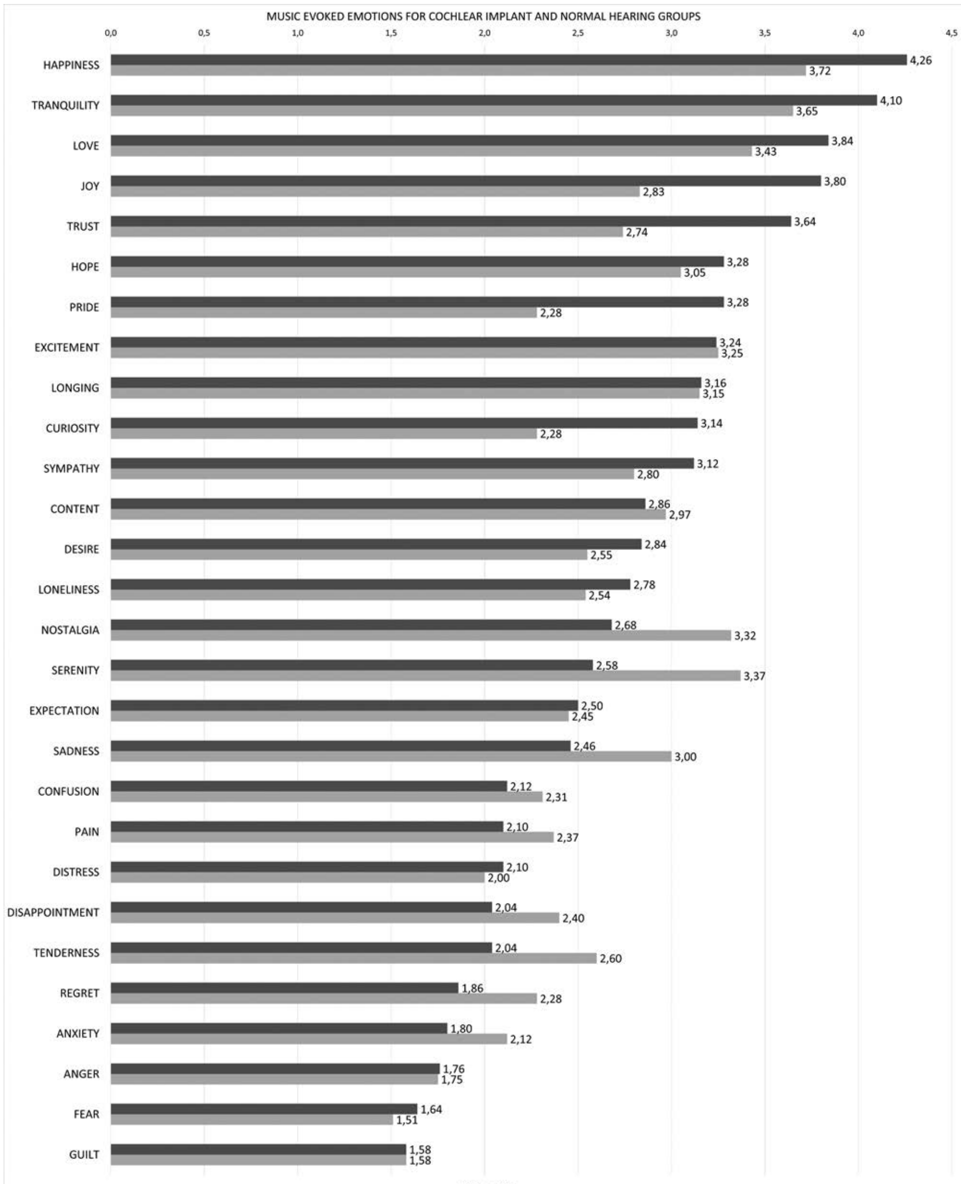

Fig. 1. Ranking of music-evoked emotions in cochlear implant and normal hearing groups.

The highest loads (>0.70) for the "Rage-Anxiety" factor came from anger, anxiety, and fear. The second factor, "Happiness—Pride," obtained the highest scores for happiness, pride, longing, and trust. Only two variables, sadness, and pain contributed to loads of the third factor, "Sadness—Pain." The fourth factor, "Sympathy—Tenderness," had the highest load of sympathy. The fifth and final factor, "Serenity—Satisfaction," received the highest load of serenity.

Emotion Mechanisms

The emotional mechanisms in both the CI and the NH groups are presented in Figure 2. In the CI group, the items on lyrics, and rhythmic entrainment ranked the highest, while the items on brainstem reflex and cognitive assessment/visual imagery ranked the lowest. Similarly, in the NH group, the rhythmic entrainment, and lyrics items ranked the highest, while the brainstem reflex and visual imagery items ranked the lowest.

CIs Versus NH

A Mann–Whitney U test was run to determine if there were differences in emotion ratings, emotion mechanism ratings, listening hours, and EFP between CI and NH groups. The results showed a statistically significant difference for episodic memory mechanism (U = 993, z = −3.68, P = 0.001), listening hours (U = 789, z = −4.73, P = 0.001), nostalgia (U = 1000.5, z = −3.13, P = 0.001), and serenity (U = 993, z = −3.68, P = 0.001), in which the NH group scored higher. On the other hand, the CI group scored higher in happiness (U = 993, z = −3.68, P= 0.001), joy (U = 993, z = −3.68, P = 0.001), trust (U = 993, z = −3.68, P = 0.001), pride (U = 993, z = −3.68, P = 0.001), and curiosity (U = 993, z = −3.68, P = 0.001).

CI groups

The emotions and emotion mechanism ratings in the three CI groups and bimodal users are presented in Tables 5 and 6 and

TABLE 4. Factor loadings

	Rotated Component Matrix				
			Component		
	Anxiety—Anger	Happiness—Pride	Sadness—Pain	Sympathy—Tenderness	Serenity—Satisfaction
Anxiety	**0.832**	−0.049	−0.174	0.158	−0.099
Anger	**0.793**	0.213	0.062	−0.284	0.003
Fear	**0.739**	−0.089	0.216	0.225	0.219
Anticipation	**0.680**	0.233	0.009	0.267	0.047
Guilt	**0.648**	−0.001	0.217	0.430	0.091
Distress	**0.614**	−0.071	0.163	−0.019	−0.140
Regret	**0.609**	0.191	0.293	0.210	0.297
Disappointment	**0.573**	0.287	0.370	−0.006	−0.375
Loneliness	**0.571**	0.164	0.406	−0.063	−0.397
Happiness	−0.116	**0.807**	−0.025	−0.018	0.040
Pride	0.187	**0.739**	0.279	0.031	0.017
Longing	0.129	**0.712**	0.016	0.096	0.149
Trust	0.337	**0.707**	−0.029	0.137	−0.008
Love	−0.055	**0.693**	0.167	0.272	0.124
Desire	0.277	**0.467**	0.239	−0.212	0.212
Joy	−0.180	**0.516**	0.505	0.164	0.083
Sadness	0.245	0.160	**0.780**	0.147	−0.089
Pain	0.347	0.021	**0.779**	0.086	0.117
Sympathy	0.128	0.253	−0.097	**0.735**	0.136
Tenderness	0.270	−0.019	0.271	**0.647**	−0.222
Tranquility	−0.297	0.455	0.307	**0.477**	0.087
Curiosity	0.424	0.168	0.321	**0.475**	0.035
Serenity	0.053	0.108	−0.034	0.013	**0.801**
Satisfaction	−0.101	0.182	0.396	−0.178	**0.601**
Hope	0.038	0.445	−0.106	0.339	**0.595**

Figures 3 and 4. Due to smaller and uneven sample sizes and the high number of multiple comparisons, emotion ratings were excluded from the statistical analysis considering the exceptionally low statistical power (below 20%). Consequently, the Kruskal–Wallis H test was run to determine if there had been differences in emotion mechanism ratings, listening hours, and EFP in PreD-EI, PreD-LI, and PostD CI recipients, and bimodal and unilateral CI recipients. Only the median episodic memory ratings were statistically and significantly different between PreD-EI, PreD-LI, and PostD CI groups, $X^2(2) = 8.954$, $p = 0.002$. Pairwise comparisons were performed using Dunn's (Dunn 1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. This post hoc analysis revealed statistically significant differences in median episodic memory scores between the CI groups PreD-EI (2.38) and PostD (3.45) ($p = 0.009$), but not between the PreD-EI and PreD-LI (3.00) and the PreD-LI and PostD groups.

Music Listening Data and Demographics in the CI Group

Correlation coefficients were analyzed for chronological age, hearing loss age, CI age, listening hours, EFP, and questionnaire scores. Since there is a high number of comparisons, only statistically significant correlations ($p < 0.05$) are presented in Table 7. Overall, our analysis revealed a general trend of significant correlations between EFP and various emotions, such as longing ($r = 0.51$) and love ($r = 0.52$), and emotion-evoking mechanisms, such as cognitive appraisal ($r = 0.44$) and evaluative conditioning ($r = 0.47$).

DISCUSSION

This study provided information on the emotions evoked by music and the associated mechanism in CI recipients with varying hearing loss onset and implantation ages. We observed the highest rankings for rhythmic entrainment and lyrics as emotion-evoked mechanisms in the CI group and significantly lower rankings of episodic memory in prelingually deafened-early implanted CI recipients compared to prelingually deafened-late implanted and postlingually deafened CI recipients. We also found statistically significant correlations between EFP, chronological, hearing loss, and CI age demographics and various emotions and mechanisms. We propose that these factors should be considered in music-related interventions in CI recipients, including music training, music-inclusive auditory rehabilitation, and music therapy. In addition, our findings confirmed prior research showing the influence of early auditory experiences on the auditory and musical perception skills of different subgroups of CI recipients.

Rhythmic Entrainment and Lyrics

Except for episodic memory, emotional mechanisms were similar among CI groups and between CI and NH groups. There were differences across groups in terms of emotion mechanism ranking orders, but lyrics and rhythmic entrainment are the most important aspects of the musical mechanisms that evoke emotion in the CI and NH groups. This finding on the effect of rhythmic entrainment is consistent with earlier studies about the ranking of the emotion mechanisms in NH listeners (Juslin et al. 2016) and the good rhythm perception abilities of CI recipients

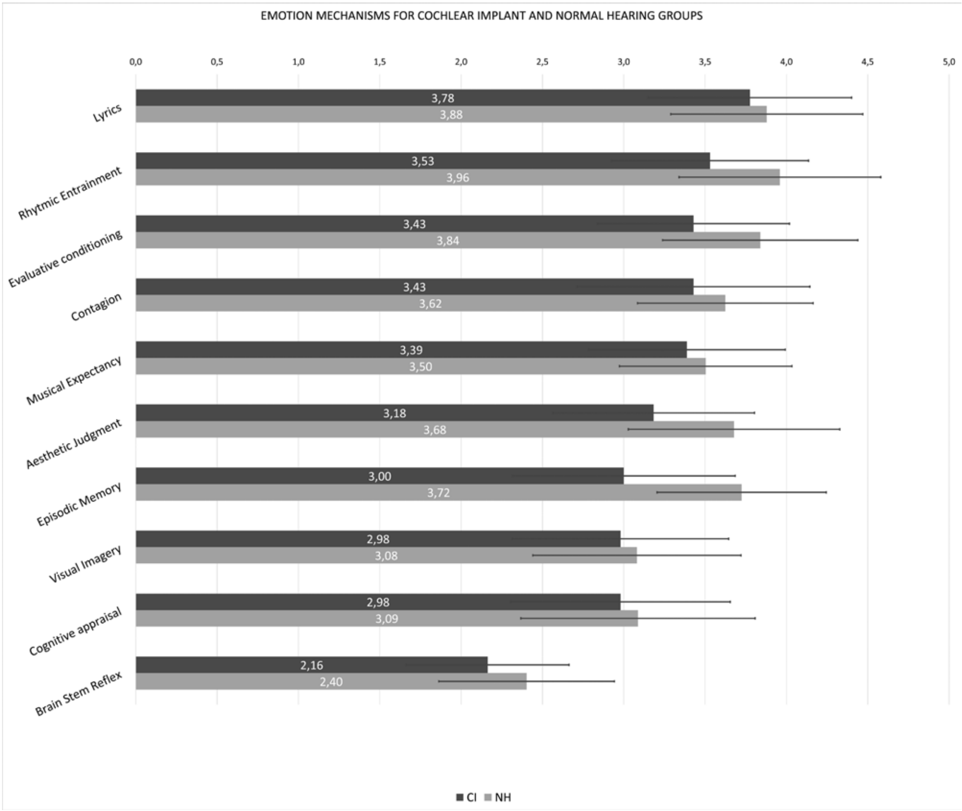

Fig. 2. Ranking of emotion mechanisms in cochlear implant (CI) and normal hearing (NH) groups.

TABLE 5. Emotion ratings of three cochlear implant recipient groups

Emotions	PreDEI	PreDLI	PostD
Happiness	4.19	4.15	4.27
Tranquility	4.13	3.93	4.18
Love	3.94	3.54	4.09
Joy	3.69	3.31	4.00
Trust	3.75	3.46	3.36
Hope	3.13	3.15	3.27
Pride	3.25	3.46	3.00
Excitement	2.94	3.23	3.09
Longing	2.38	3.69	3.36
Curiosity	3.56	3.23	3.18
Sympathy	3.44	3.08	2.82
Content	2.56	3.23	2.55
Desire	2.50	2.92	3.09
Loneliness	2.94	2.85	2.55
Nostalgia	2.25	2.77	3.00
Serenity	2.50	1.85	2.45
Expectation	2.50	2.85	2.09
Sadness	2.50	2.62	2.36
Confusion	2.25	2.23	1.73
Pain	2.25	2.31	1.82
Distress	2.13	2.15	2.18
Disappointment	1.94	2.62	1.45
Tenderness	2.06	2.31	2.00
Regret	1.88	2.23	1.45
Anxiety	2.06	1.69	1.36
Anger	1.81	2.08	1.36
Fear	1.88	1.46	1.27
Guilt	1.75	1.54	1.27

PostD, postlingually deafened; PreDEI, prelingually deafened, early implanted; PreDLI, prelingually deafened, late implanted.

TABLE 6. Emotion ratings of unilateral and bimodal cochlear implant recipient groups

Emotions	Unilateral	Bimodal
Happiness	4.20	4.14
Tranquility	4.08	3.95
Love	3.86	3.59
Joy	3.67	3.59
Trust	3.52	3.41
Hope	3.18	3.14
Pride	3.24	3.18
Excitement	3.09	3.14
Longing	3.14	3.18
Curiosity	3.32	3.14
Sympathy	3.11	3.00
Content	2.78	2.73
Desire	2.84	2.91
Loneliness	2.78	2.77
Nostalgia	2.67	2.86
Serenity	2.27	2.31
Expectation	2.48	2.41
Sadness	2.49	2.45
Confusion	2.07	1.73
Pain	2.13	1.86
Distress	2.15	2.32
Disappointment	2.00	1.82
Tenderness	2.12	2.05
Regret	1.85	1.82
Anxiety	1.70	1.91
Anger	1.75	1.64
Fear	1.54	1.64
Guilt	1.52	1.50

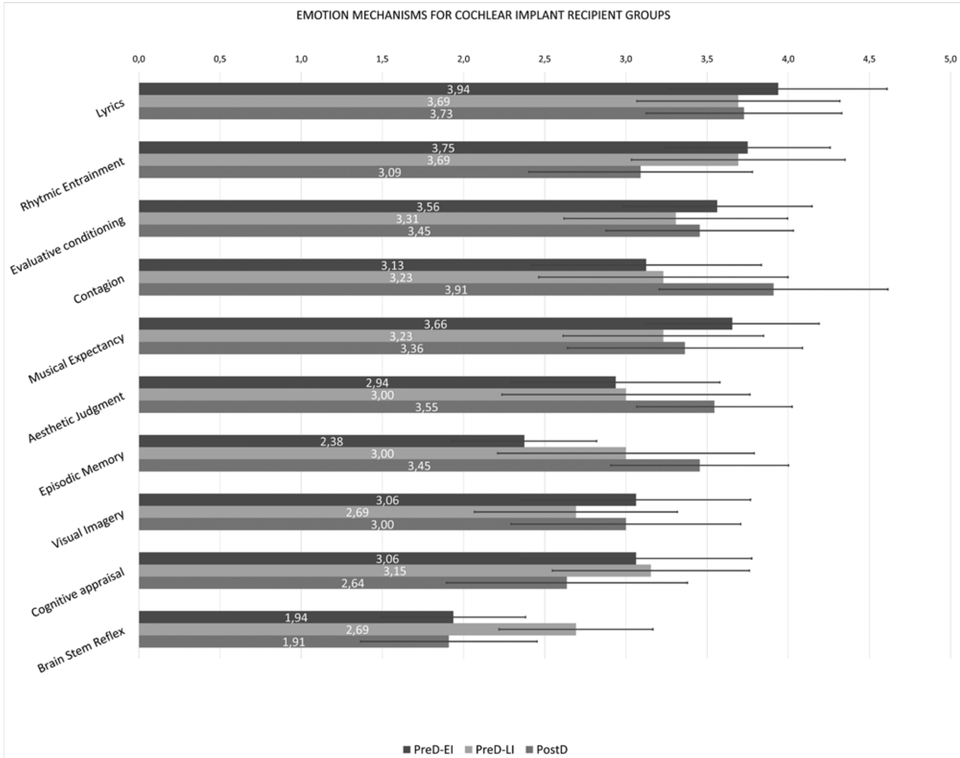

Fig. 3. Ranking of emotion mechanisms in prelingually deafened—early implanted (PreD-EI), prelingually deafened—late implanted (PreD-LI), and postlingually deafened (PostD) groups.

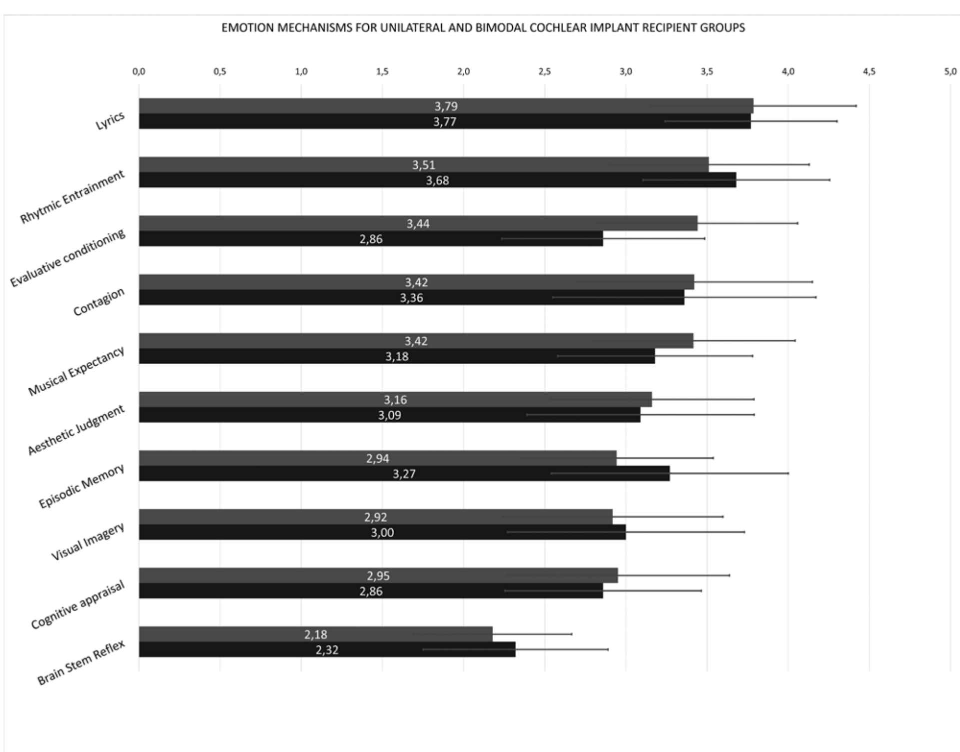

Fig. 4. Ranking of emotion mechanisms in unilateral and bimodal CI groups.

(Drennan & Rubinstein 2008; Phillips-Silver et al. 2015; Jiam & Limb 2019). Rhythm affects musical emotions through anticipation and prediction by releasing dopamine (Salimpoor et al. 2011) and triggering reward circuits in the brain. Therefore, focusing on rhythmic entrainment can be regarded as a reliable method for eliciting music-related emotions in CI recipients.

TABLE 7. Significant correlation coefficients in music listening data, demographics, and questionnaire scores for cochlear implant recipient groups

		Age	HL Age	CI Age	EFP	PTA
	LH				0.28	0.50
	EFP	−0.31	−0.35			
Emotions	Loneliness	−0.36				
	Nostalgia	0.35		0.34		
	Pride	0.40	−0.34	−0.33		
	Expectation				0.38	0.41
	Longing				0.51	
	Love				0.52	
	Happiness				0.36	
	Pride				0.46	
	Trust				0.37	
	Curiosity				0.46	
	Sympathy				0.36	
	Anger					0.40
	Anxiety					0.41
Mechanism	Rhythmic Entrainment	−0.34			0.40	
	Musical Expectancy	−0.34		−0.31		
	Cognitive Appraisal	−0.35			0.44	
	Brainstem Reflex				0.37	
	Episodic Memory				0.31	
	Evaluative Conditioning				0.47	
	Visual Imagery				0.32	
	Contagion				0.30	
	Lyrics				0.36	

CI, cochlear implant; EFP, emotion feeling percentage; HL, hearing loss; LH, listening hours; PTA, pure-tone average.

A high ranking of lyrics is not surprising, considering that CI recipients rely more on lyrics than pitch changes or melodies to recognize songs (Olszewski et al. 2005; Vongpaisal et al. 2006; Hsiao 2008). However, the accessibility of lyrics compared to other components of the music and how lyrics affect music-evoked emotions should be considered. Lyrics often can be found on album booklets or in the lyrics options in digital streaming services. Thus, it is highly possible that listeners with hearing loss, CI, or hearing aids may be more inclined to read lyrics to have a better perception of music. Although the present study did not assess how often CI recipients read the lyrics when available, it should be noted that music-evoked emotion is also a multimodal experience in that regard. It may be beneficial to include lyrics as readable material in music-related interventions to provide a better experience for CI recipients.

Episodic Memory

The most notable finding of this study is that the episodic memory mechanism ranked significantly lower in CI recipients compared to NH participants and in PreD-EI CI recipients compared to PostD CI recipients. These results suggest that the limited perception of music offered by electrical hearing (CI) negatively affects episodic memory, whereas acoustic hearing (NH or hearing aid) stimulates the retrieval of autobiographical memories connected with music, particularly those formed at a young age. This observation is expected and natural for postlingually deafened individuals with musical memories from their NH period and a musical "reference" for their current musical experiences. According to the study by Fuller et al. (2019), these references may lead to less appreciation of music post-implantation in comparison to pre-implantation. Therefore, rehabilitative and training procedures for postlingual CI recipients should differ from those for prelingual CI recipients and incorporate approaches to facilitate acceptance or acclimatization to new forms of music related to episodic memories.

In contrast, PreD-EI CI recipients require a different approach. Although our findings do not show that PreD-EI CI recipients have no musical memory, findings reveal an insufficient association between episodic memory and music-evoked emotions. Professionals must consider the lower preference for episodic memory in PreD-EI. This is rooted in the fact that music feels pleasant and arousing when it is experienced as familiar and autobiographically salient (Salakka et al. 2021), and autobiographical memories induced by music are the most episodically rich of all sensory cues (Belfi et al. 2022) in NH individuals. Besides, CI participants in the Vannson et al. (2015) study showed an unexplained enjoyment preference toward happy music, compared to NH listeners who enjoyed both happy and sad music similarly. Huron (2011) stated that the enjoyment of sad music might be related to conditioning and past experiences. Hence, the lower ranking of episodic memory may explain the preference of CI recipients for happy music.

In addition, our findings should be interpreted in light of prior reports of enhanced music perception and emotion recognition abilities in bimodal CI recipients and/or CI recipients with residual acoustic hearing (Kong et al. 2012; Giannantonio et al. 2015; Shirvani et al. 2016; Yüksel et al. 2019). Almost every study on the topic demonstrates that acoustic hearing impacts performance in music-related tasks, and our study supports this conclusion. Specifically, we found that PostD CI recipients utilized episodic memory similarly to NH participants (scores of 3.45 vs. 3.72, respectively), while the PreD-EI group scored episodic memory significantly lower compared to the PostD and PreD-LI groups. Notably, the PostD and PreD-LI groups included CI recipients who previously had a NH or used hearing aids, which may have helped them to have meaningful musical experiences. Based on these findings, we suggest that any useful acoustical hearing should be fostered and included in music-based interventions before and during CI use to enhance overall music-related performance.

Ranking of Emotions

Music researchers are curious about the universality and uniqueness of music-evoked emotions, and studies in CI recipients may offer a unique perspective on this topic. Differences in long-term auditory exposure and deprivation in CI recipients are almost impossible to replicate in NH listeners. Therefore, even though CI recipients may not represent a distinct cultural group, our data may provide some insights into the sensory aspects of music-evoked emotions. CI recipients in our study evaluated basic and positive emotions (e.g., happiness, joy, love) higher than negative and complex emotions, similar to NH participants in our study and in the literature (Zentner et al. 2008; Juslin et al. 2016; Saarikallio et al. 2021). The influence of positive emotions in music is also reflected in the PCA, which revealed three distinct emotion dimensions for positive emotions, including happiness-pride, sympathy-tenderness, and serenity-satisfaction compared to two distinct emotion dimensions for negative emotions, including anxiety-anger and sadness-pain in CI recipients. The power of positive and simple emotions in music in the present study demonstrates that emotions in music are partially independent of sensory perception and early auditory experiences. When this is considered in conjunction with the fact that the highest-rated emotion mechanisms in both groups (CI and NH) were lyrics and rhythm, we can speculate that the "content" of music, when combined with rhythm, strongly affects emotional responses to music, regardless of previous auditory experiences.

Music Listening Data, Demographics, and Age Effect

CI recipients (70.4%) reported similar emotional feeling percentages to NH participants (66.3%), even though differences between average music listening hours were significant (5.86 vs. 13.63 hours/wk). This finding is promising for music-based auditory rehabilitation. As stated previously, emotions can aid in changing or acquiring behaviors. Our finding that CI recipients report high EFP shows that evoking emotions in music is possible regardless of sensory limitations in music perception. This emphasizes the importance of emotionally meaningful musical interventions in CI recipients. Moreover, EFP showed the highest number of significant correlations with questionnaire items, including several emotions, almost all mechanisms (8 of 10), and weekly average music listening hours. This strong relationship also suggests that professionals may ask a very simple question about the frequency of music-evoked emotions in patients and have a broader perspective that can impact management.

Age-related demographics had significant effects on various emotions (pride, nostalgia, and loneliness), emotion mechanisms (rhythmic entrainment, musical expectancy, and cognitive appraisal), and EFP. Chronological, hearing loss, and implantation ages are related to auditory exposure and musical experiences, hence some differences in music-evoked emotions are expected. The decrease in the score for loneliness with increasing chronological age can be explained by previous findings which showed that older listeners reported a stronger emotional reactivity for positive emotions than negative emotion categories, compared to younger adults (Vieillard & Gilet 2013; Castro & Lima 2014). The increasing score of nostalgia with CI and chronological age is a consistent finding with our findings on episodic memory (i.e., the lowest and highest episodic memory scores obtained in PreD-EI and PostD groups, respectively), which reflects increasing past experiences with age. Pride, on the other hand, requires a more culturally specific commentary and probably reflects the changing political environment and generational differences, which we believe is well beyond the scope of the current study.

However, since older CI recipients tend to have postlingual hearing loss and higher CI age (e.g., CI and hearing loss ages both have a direct relationship with chronological age), our findings in this category should be evaluated with careful attention. Significant correlations observed for CI and hearing loss age, emotions (nostalgia and pride), and musical expectancy mechanism may be a result of increasing chronological age.

Clinical Implications

The clinical implications of our study can be summarized with four key points. First, rhythm, and lyrics are not only vital for better music perception but also for evoking emotions in music. Consequently, focusing on rhythmic and lyric cues in auditory interventions for CI recipients can be beneficial both in the perceptional and emotional aspects. Second, regardless of music listening hours or auditory experiences, CI recipients have emotional connections with music like NH individuals. Therefore, music-centered interventions should contain meaningful experiences and be emotionally stimulating, especially for younger, and newly implanted CI recipients, whether it be during habilitation, training, or therapy. Third, emotion-evoking mechanisms can be different for CI recipients with different auditory experiences (e.g., hearing loss etiology, progression, or onset age), and early deafened-implanted CI recipients may have limited episodic memory for emotions in music. Hence, depending on the perspective, music-based auditory interventions may avoid using procedures related to episodic memory or may include some methods to evoke new memories associated with music. Last, professionals can include simple questions regarding music-evoked emotions (preferably questions about feeling emotions or an emotional connection with music) if music is a part of their rehabilitative routines. This way, more comprehensive approaches can be developed for CI recipients.

Limitations of the Current Study

There are a few limitations of the study that need to be addressed. First, the emotional terms we included in this study and similarly those in previous studies are often not "clearly" differentiated from each other. It remains a challenge to define specific emotions that do not overlap with each other. Emotions experienced in real life can also be expressed with multiple similar words, or a single word can be used to define multiple experiences. Although the factor analysis provides broader factors that can be discussed, the present study can benefit from more well-defined emotional words.

Second, the level of education is considerably heterogeneous in the present study since we included participants with diverse hearing loss etiologies, auditory experiences (e.g., prelingual and postlingual CI recipients), and ages. NH participants in our study are mostly young, highly educated adults, and we believe such demographics can serve as a reliable reference for music-evoked emotions both in terms of similarity to previous studies (Juslin et al. 2016; Saarikallio et al. 2021) and the high proportion of music listeners in young adults.

The subjective nature of self-reported measures should also be considered in the present study. Although there is no previous discussion on the bias that may occur in music and emotion studies, it is known that self-reported measures are prone to bias that may result in a measurement error (Bound et al. 2001). The bias often occurs with cognitive processes, social desirability, and survey conditions (Bauhoff 2011). Even though music-evoked emotions are not heavily connected with these aspects, the presence of bias cannot be disregarded.

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The authors have no conflicts of interest to declare.

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