The effect of music on auditory perception in cochlear-implant users and normal-hearing listeners

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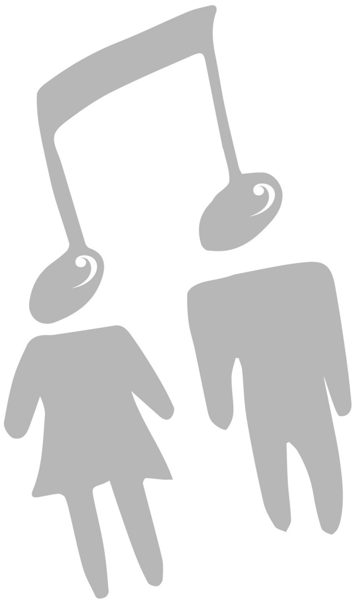
Chapter 10

General discussion and conclusions



This thesis focused on perception of music and speech in CI users. While (re-)gaining speech perception is the most important goal for CI users, music perception is also highly valued (Drennan and Rubinstein 2008). However, music perception and enjoyment is often poor in CI users (Limb and Roy 2014; McDermott 2004). This thesis first described music perception in terms of subjective and behavioral measures in a large cohort of CI users. The subjective measures were important because music ultimately conveys emotion, and the effect of music on one's emotional state may differ from one individual to another (Zatorre and Salimpoor 2013; Salimpoor et al. 2009). The behavioral measures were important to quantify CI users' music perception, which in turn is important to guide development of future devices and signal processing strategies. Theoretically, improvements in music perception may also improve music enjoyment. Improved pitch perception would most likely also improve perception of indexical cues (who is talking) and prosodic cues (how something is said) in speech, as subjective perception of music and pitch-mediated speech were correlated in our research. While it may be difficult to sufficiently improve CI technology to support good pitch perception, we secondly explored methods in the training domain that might improve perception of music and pitch-mediated speech tasks. A strong support for this idea came from the studies with both musicians who were trained previously and also with CI users who were trained directly.

One of the first parts of the thesis was an exploration of the subjective appreciation and perception of music within CI users. We hypothesized that music perception and/or enjoyment would be related to speech perception and/or quality of life (QoL). We not only had access to typical CI users (post-lingually deafened), but also to an under-studied CI group: early-deafened, late-implanted (EDLI). The comparison between these two groups revealed many important factors that can affect music appreciation and perception with CIs.

Post-lingually deafened CI users (the dominant population of CI patients) reported that the sound quality of music was poor **(Chapter 3)**. Perception of music has been reported to be poorer and less enjoyable in post-lingually deafened CI-users (Gfeller et al. 2000; Lassaletta et al. 2008; McDermott 2004; Limb and Roy 2014). Our findings re-emphasize the need of improvement of the perception of music for post-lingually deafened CI users. In contrast, EDLI CI users reported that the sound quality of music was good **(Chapter 2**), though still suboptimal. This observation in EDLI CI users is in agreement with Trehub, Vongpaisal, and Nakata (2009), who reported high music appreciation levels in pediatric CI users even though their musical pitch perception was poorer than their NH peers. These results suggest that music perception may not be the only (or even main) determinant of music appreciation, and that the amount of acoustic hearing experience before implantation may greatly affect music sound quality perception.

The relationship between subjective perception of music and quality of life (QoL) also differed between these two groups of CI users. In post-lingually deafened CI users, music enjoyment and perception was related to QoL **(Chapter 3)**, similar to findings by Lassaletta et al. (2007) who showed that music appreciation was correlated to the generic QoL in a smaller number of post-lingually deafened CI-users. However, we found no significant correlation between music appreciation and QoL in EDLI CI users **(Chapter 2)**. This difference may be because of differences in music appreciation between post-lingually deafened and EDLI CI users, with "perfect" perception of music being more important to post-lingually deafened CI users, based on their previous acoustic experience with music. Providing rehabilitation to post-lingually deafened CI users might increase their QoL. There was no association between behaviorally measured speech perception and subjective music perception for either group. A significant effect of the perception of the elements of music and subjective measure of hearing abilities (the SSQ questionnaire) was observed only in the post-lingually deafened CI users. Philips et al. (2012) did show a correlation between a more natural sounding music and speech reception thresholds in quiet and noise, in a small group of post-lingually deafened CI users. Even though the evidence from the subjective studies is weak, improving the perception and enjoyment of music could possibly affect both QoL and speech perception. Further research needs to be conducted to determine whether better music perception is linked to higher QoL and better speech perception in CI users.

In terms of rating the subjective perception of the music elements, post-lingually deafened CI users rated rhythm as the easiest element and melody as most difficult element of music to perceive, in accordance with previous literature (Gfeller et al. (2000); **Chapter 3**). In contrast, EDLI CI users rated melody the easiest and rhythm the most difficult element **(Chapter 2)**. One explanation for these contradictory patterns of results is that, different from post-lingually deafened CI users, EDLI CI users have no previous acoustic listening experience with music. EDLI CI users may develop music concepts and patterns differently with electric hearing, which might differ from the normal, acoustic listening experience. Given the limits of pitch perception with the CI, it is curious that EDLI CI users would rate melody higher than rhythm elements. While pitch is represented different and more coarsely in electric hearing than in acoustic hearing, EDLI CI users seemed able to develop meaningful melodic patterns; given their previous acoustic hearing, post-lingually deafened CI users may have greater difficulty adapting to melodic patterns with electric hearing. Previous studies have also shown that amplitude modulation detection is poorer in pre-lingually than in post-lingually deafened CI users (De Ruiter et al. 2015). If temporal envelope processing was poorer, EDLI CI users may have had greater difficulty with rhythm perception than did the post-lingually deafened CI users.

The subjective evaluation of music showed that both perception and enjoyment remained unsatisfactory in both CI subject groups. Because music perception (and thus, appreciation) is limited by the poor pitch perception provided by CIs, we investigated how this limitation might also affect perception of pitch mediated speech. Our research showed that post-lingually deafened CI users exhibited abnormal voice gender categorization **(Chapter 4)** and vocal emotion identification **(Chapter 5)**, relative to NH listeners. Our findings extended those from previous literature (Xin, Fu, and Galvin 2007; Winn, Chatterjee, and Idsardi 2011), and revealed further details regarding CI users' perception of voice gender and vocal emotion, suggesting that the extent of the problem may be larger than what was previously reported.

In NH listeners, voice gender categorization is mostly based on perception of F0 and vocal tract length (VTL), although there are other acoustic cues such as breathiness (Holmberg, Hillman, and Perkell 1988; Van Borsel, Janssens, and De Bodt 2009) or intonation (Fitzsimons, Sheahan, and Staunton 2001). In our study, NH listeners indeed made effective use of both VTL and F0 cues, even when listening to the spectro-temporally degraded CI simulations. Our findings showed, for the first time, that CI users almost exclusively relied on F0 cues, and did not make use of the VTL cues for voice gender categorization. This finding seems at first surprising as there is a long history of research that focused on deficiencies of voice pitch (F0) perception in CI users (Kong and Carlyon 2010; Oxenham 2008; Kong et al. 2009; Gfeller et al. 2007; Fu, Chinchilla, and Galvin 2004; Başkent et al. 2016). Only after the systematic manipulation of the voices, as we did in this study, it was revealed that CI users can utilize F0 cues, even if they are only weakly delivered by the device. What seems to be more problematic is the perception of VTL cues, which has been rarely studied in CI listeners.

Given that the spectro-temporal degradation was present in the signal of both the real CIs and the CI simulations, the difference in VTL perception between NH and CI listeners may be due to properties of electric stimulation. A study by Gaudrain and Başkent (2015) showed no differences for the just-noticeable-difference between VTL and F0 perception using a fixed number of sinewave vocoded channels in NH listeners. Changing the number of channels had a bigger effect on VTL than on F0 perception. Given the limited spectral resolution (due to current spread among the small number of implanted electrodes), an improvement in VTL perception may not be feasible in CI users (Gaudrain and Başkent 2015). Another explanation might be that CI users do perceive a weak VTL, but are unable to use it. If the latter is true a musical training providing for example timbre or VTL cues, might enable usage of VTL and therewith improve gender recognition. Gender categorization is found to be abnormal in CI users in comparison to NH listeners, due to different weighting of voice cues. Future studies could focus on adding other acoustic cues (e.g., breathiness or intonation) to the analyses to further unravel differences in perception between CI users and NH listeners.

Chapter 5 focused on another pitch-based speech task: vocal emotion identification. Emotions can be divided according to arousal and valance. Arousal differentiates emotions with a high (anger) or low arousal (sad). Valence differentiates positive (happy) from negative emotions (sad). Vocal emotion identification is mostly based on arousal in general (Russell and Mehrabian 1977). In our vocal emotion identification study, we used pitch range and mean pitch as measures of arousal based on previous research (Xin, Fu, and Galvin 2007; Goudbeek and Broersma 2010). Results showed that NH listeners used mean pitch for emotion identification for both unprocessed stimuli and acoustic CI simulations. CI users relied on pitch ranges, and did not cue to mean pitch. CI users might not be able to use mean pitch as a cue due to the poor spectral resolution. Instead they appeared to utilize the more easily perceived pitch range cue. CI users had a poorer vocal emotion identification compared to NH subjects listening to unprocessed speech or CI simulations. These findings are in accordance to other studies that showed CI users to have a different identification of emotions based on the cues available via the CI (Winn, Chatterjee, and Idsardi 2011; Xin, Fu, and Galvin 2007).

The impaired subjective and behavioral perception of pitch-related speech and music perception as described in **Chapters 2, 3, 4 and 5** re-emphasized the need to improve pitch perception in CI users. One way to improve music perception (and perhaps pitch perception) might be through musical training. NH musicians have been shown to have advantages over non-musicians in perception of music, as would be expected. More interestingly, musicians also have been shown to perform better in some speech-related tasks, displaying a cross-domain transfer of learning (Parbery-Clark et al. 2009; Schon, Magne, and Besson 2004; Besson et al. 2007; Thompson, Schellenberg, and Husain 2004; Chartrand and Belin 2006; Patel 2014; Micheyl et al. 2006; Kraus and Chandrasekaran 2010; Kraus, Zatorre, and Strait 2014). Previous studies in NH listeners have shown the largest musician effect for speech understanding with speech maskers, with smaller or no effects for speech in noise (Ruggles, Freyman, and Oxenham 2014; Parbery-Clark et al. 2009; Boebinger et al. 2015; Swaminathan et al. 2015; Zendel and Alain 2013). Several hypotheses have been developed about what specifically may be helping speech perception from music training. Better perception of auditory cues may provide a bottom-up advantage (Herholz and Zatorre 2012; Zatorre and Baum 2012; Micheyl et al. 2006). Alternatively, enhanced auditory cognitive functioning provide a top-down advantage (Strait et al. 2010; Kraus, Zatorre, and Strait 2014; Zendel and Alain 2013).

Both advantages provide a benefit when listening to spectro-temporally degraded music and speech, as is the case in CI-processed signals. Ideally, this idea would be tested with musically trained CI users. However, it was difficult to find CI users with extensive musical experience before and after implantation in our medical center **(Chapter 6)**. To explore whether musical experience might contribute to spectro-temporally degraded music and speech perception, we tested NH musicians and provided training directly to actual CI users. NH musicians were used as a model of long-term musical training.

To explore the musician effect on degraded music and speech perception, we have recruited NH musicians (defined as having 10 or more years of musical training) and non-musicians **(Chapters 7 and 8)**. We have tested perception of music (melodic contour identification), speech (sentence recognition in quiet and in noise), and pitch-mediated speech (vocal emotion identification, voice gender categorization). Spectro-temporal degradation was implemented via 8-channel acoustic CI simulations. For music, the degradation significantly reduced the performance in NH musicians and non-musicians; musicians exhibited better music performance than did non-musicians. This confirmed that within-domain learning effects from musical training are robust, and preserved even when heavy degradations are imposed on the music stimuli.

NH musician performance was very good for vocal emotion identification and voice gender categorization. A cross-domain musician effect for pitch-related speech tasks was observed in the CI simulations. **Chapter 5** showed that NH listeners made use of the mean pitch for emotion identification compared to CI users. NH musicians seemed better able to perceive mean pitch in the CI simulations and performed better than non-musicians. **Chapter 7** showed musicians were able to better utilize F0 cues for voice gender categorization. If a better perception of pitch is the underlying mechanism for the musician effect in pitch-related speech tasks, this could imply that musical training with targeted pitch perception could enhance CI users' emotion identification and voice gender categorization. For speech perception, the picture was more complicated. We found no musician advantage for intelligibility with unprocessed speech, and only a small advantage for word identification in one noise condition with the CI simulation. These results are in agreement with previous studies that found small or inconsistent transfer of the musician effect to speech tasks (Ruggles, Freyman, and Oxenham 2014; Parbery-Clark et al. 2009; Boebinger et al. 2015; Swaminathan et al. 2015; Zendel and Alain 2013). The present results add to body of literature showing a musician advantage for pitch-mediated speech perception, even under conditions of spectro-temporal degradation **(Chapter 7 and 8)**. The contribution from other skills potentially improved by music training (e.g., better segregation of stimuli, which was not studied here), remain to be determined.

We note that sinewave vocoders were used for the CI simulations to study the musician effect. Sinewave vocoders were used because they provide better representation of the temporal envelope, compared to noise-band vocoders (e.g., Fu et al. 2005). Alternatively, "low-noise" noiseband vocoders have been shown to improve envelope fidelity in CI simulations (Whitmal et al. 2007). One disadvantage associated with sinewave vocoding is the proliferation of side bands around the carrier frequency that might provide additional spectral cues that might benefit pitch perception (Souza and Rosen 2009). In this study, such sideband cues were available to both the NH musicians and non-musicians; only the NH musicians seemed able to use this cue if it was indeed meaningful. Sinewave carriers also create the perception of a somewhat constant pitch; spectral envelope information (the relative amplitudes across the sinewave carriers) may have been better perceived by the NH musicians. The sinewave vocoders implemented in these studies did not simulate channel interaction that typically exists in CI users. Crew et al. (2012) used a channel mixing technique to introduce different degrees of channel interaction in sinewave vocoded CI simulations, and found that melodic pitch perception worsened as the channel interaction increased. Also, only 8-channel vocoders were used for the CI simulations. CI users' functional spectral resolution has been shown to range from 4-12 channels (Friesen et al. 2001; Xu, Thompson, and Pfingst 2005). It is unclear whether increasing or decreasing the number of channels in the present CI simulations would have enhanced or reduced the musician effect. There are also tradeoffs between the number of channels and then temporal envelope cutoff frequency (160 Hz in this study). When there are fewer channels, listeners can utilize higher frequency temporal envelope information. However, when there are a sufficient number of spectral channels, the temporal envelope filter can be reduced to 50 Hz or less with no effect on performance (Fu et al., 2004). Performance in the tasks used in these studies (vocal emotion identification, gender categorization, melodic contour identification) partly depended on temporal and spectral envelope cues. Future studies may manipulate these cues (number of channels, vocoder carriers, temporal envelope cut-off frequency, etc.) to further explore the musician effect with CI simulations.

In general, the results from this thesis showed that the musician advantage was stronger as the importance of pitch in the listening task increased. This supports the idea that the musician effect is strongly rooted in enhanced pitch perception. If musician advantage was mainly due to better cognitive processing (which was not tested here but in other studies (Zendel and Alain 2013; Kraus, Zatorre, and Strait 2014; Herholz and Zatorre 2012; Zatorre 2013), the musicians in our study would have performed better in all perception tasks, which was not the case. The results suggest that musical training before (and possibly after) implantation might offer some advantage in pitch processing that may persist under conditions of spectro-temporal degradation. This advantage might strongly benefit perception of prosodic and indexical cues in speech, as well as melodic pitch in music.

In the last part of the thesis, we implemented a feasibility study for training actual CI users

(Chapter 9). as a first step toward implementing a musical training program in the clinic. This study explored whether any training improvements could be observed in such a short period of time (6 weeks), and if so, which training approach was most effective. A small group of CI users, representing a typical group of older, post-lingually deafened CI users, was trained for six weeks. Three different training methods were compared: individualized musical training, group music therapy and group non-musical training. To be consistent with our previous study with NH musicians and non-musicians **(Chapter 8)**, CI users were tested on speech intelligibility, vocal emotion recognition, and melodic contour identification before and after training. Similar to NH musicians, a benefit for the trained task was also observed in CI users; post-training improvements in melodic contour identification were observed for the individualized musical training group. What was perhaps more interesting is that post-training improvements were also observed in the music therapy group for vocal emotion identification, a pitch related speech task. This suggests that a specific task can be trained in a short period of time, as both melodic contour and emotion identification were trained in the musical training and the music therapy group, respectively. Similar to NH musicians, perception of pitch-mediated speech can be trained in CI users. Future studies may include longer training periods and intermittent behavioral testing during training.

There was no transfer of training benefit for speech intelligibility for any of the three training methods. These findings are in agreement with the mixed results observed in previous studies (Patel 2014; Lo et al. 2015). However, it is still unclear whether improvements might be observed with a larger subject group or a longer training period. We find it promising that at least one training approach (music therapy) improved one non-music task (vocal emotion identification). Supporting this optimism, the CI users in the music therapy group reported a subjective improvement in music perception, in line with recent literature (Hütter et al. 2015). Together with the musician effect observed in NH listeners, these findings have positive implications for music training in CI users. Music training could improve CI users' music perception (and maybe also speech perception), which in turn could improve music enjoyment (Fuller et al. 2013), which in turn could improve QoL (Fuller et al. under revision).

Overall, our findings with musicians suggest that musical experience before (and possibly after) implantation might improve CI outcomes. This might be especially true for children implanted at a very young age, who develop speech and music patterns exclusively via electric hearing during the most optimal years of neuroplasticity (Houston and Miyamoto 2010; Tajudeen et al. 2010; Olszewski et al. 2005; Magne, Schon, and Besson 2006; Besson et al. 2007). Previous studies with adult CI users have shown that computer-based training can significantly improve music perception (Galvin et al. 2012; Galvin, Fu, and Nogaki 2007). Computer-based music training has also been shown to improve Mandarin-speaking pediatric CI users' music and lexical tone perception (Fu et al. 2015). Music training might be especially effective for bimodal CI listeners (i.e., combined use of CI and hearing aid) who combine fine-structure cues from acoustic hearing with envelope cues from electric hearing (Cullington and Zeng 2011; Sucher and Mcdermott 2009). As the biggest effect was shown for music and pitch-related speech tasks (emotion identification and vocal gender categorization), an effect of training might be largest for these tasks. The effect on speech perception is unclear, as our studies combined with previous literature, show small to no effects form musical training on speech intelligibility.

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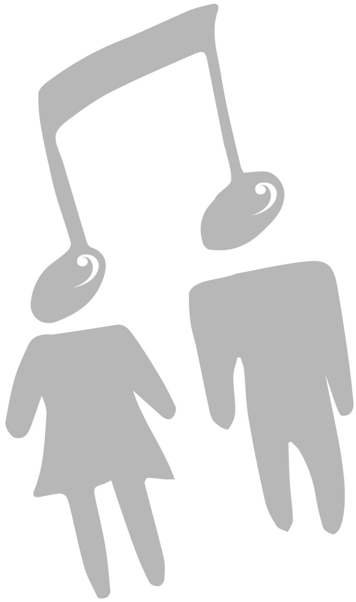
Summary
Samenvatting



SUMMARY

Cochlear implants (CIs) are prosthetic devices that restore hearing in deaf people who do not benefit from acoustic hearing aids. The perception of speech in quiet environments is for most CI users reasonably good. The perception of other acoustical signals, such as speech in noisy environments or listening to music, is still not satisfying. This thesis focused on the music perception and the potential positive effects of music training on speech and music perception in CI users. First, pitch based speech perception and music perception was subjectively and behaviorally investigated in CI users. Second, the possible beneficial effect of musical training on music and speech perception was investigated.

The music perception and enjoyment of two groups of CI users was investigated using questionnaires. As music can influence quality of life in certain patient groups, the music perception and enjoyment was also related to the quality of life. A large cohort of typical, post-lingually deafened CI users and a group of atypical CI users, the early-deafened, late-implanted group were compared. The early-deafened, late-implanted CI user is deafened during language acquisition, has been hearing deprived for a long time, and is implanted at a later age. The typical CI users is deafened after language acquisition, has a relative short period of auditory deprivation and is implanted at adult age. Early-deafened, late-implanted CI users enjoy music more, rate the quality of the sound of music higher and rate the perception of the elements of music differently than the post-lingually deafened CI users. The sound of music was rated suboptimal in both groups. A better perception of the elements of music was associated with a higher quality of life in the post-lingually deafened CI group; no such correlation was found in the EDLI CI users. The two groups of CI users rate and enjoy music differently, perhaps based on a different acoustical memory of music. Improvement is needed as both groups did rate the quality of music as suboptimal.

To see if the perception of music and its elements is also behaviorally suboptimal, CI users and normal-hearing (NH) listeners were tested for pitch based speech tasks. Voice gender categorization (a female has a higher pitched voice than a male speaker) or the identification of a vocal emotion (happy has a higher pitch than sad) was investigated. Gender categorization was tested, using a female talker that was adjusted via manipulation of two main cues of a voice: the F0, the mean pitch, and the vocal tract length, the distance from the vocal chords to the lips of a talker. Gender categorization was abnormal in CI users in comparison to NH listeners. CI users weighted the F0 of the signal higher versus a lower weighting of the vocal tract length differences, whereas NH listeners weigh both cues more evenly. The results might imply difficulties in daily life situations for gender categorization in CI users. Emotion identification was investigated using a nonce-word and four emotions. Acoustically, three cues available for emotion identification: mean pitch, pitch range and

number of dominant pitches were analyzed. The NH listeners outperformed the CI users. Emotion identification was different in CI users compared to NH listeners. NH listeners utilize the mean pitch, while CI users utilize the pitch range to identify vocal emotions. Perhaps the CI was unable to capture the mean pitch accurately enough for emotion identification. These results indicate pitch-related speech tasks such as gender categorization or emotion identification to be problematic for CI users.

To improve the perception of pitch based speech tasks or music in CI users one could, either try to improve the device via for example signal processing or device design, or one could try to improve patient related factors, such as trying to improve cognitive elements. In this thesis improvements on the patient side were chosen. Musical training has been shown to have benefits for auditory perception in NH listeners. The benefit of musical training, referred to as the 'musician effect', has been shown for music perception (within domain), but even more interesting also for speech perception in noise (transfer effect from music to speech). Areas in which CI users experience difficulties. To see whether a musician effect also exists in CI users or in the degraded CI signal tested via CI simulations, we conducted 3 studies: one subjective and two behavioral.

The first study questioned the musical background in a large cohort of post-lingually deafened CI users. The results indicated that CI users had no or minimal musical background before implantation. No correlations between the musical background and speech perception or with the quality of life were shown. Thus, no musician effect could be shown. It must be noted that the amount of musical training was so minimal in our cohort that perhaps this conclusion may not be drawn.

The second study tested the musician effect behaviorally for gender categorization. NH musicians and non-musicians listened to normal acoustical stimuli and CI-simulations. A musician effect was shown for both the normal and the CI-simulations. The musicians used F0 more than VTL. This could imply a better pitch perception in degraded conditions for musicians. This was a surprising find as the CI users also use the F0 of the signal to categorize the gender of a talker, something that was named abnormal, even more surprising while CI users were shown to have little musical training. An explanation might be that VTL is less reliably conveyed in both CI simulations and for CI users. Therefore, utilizing F0 is advantageous, as it might be the more robust cue in degraded situations.

The third study investigated the musician effect in NH listeners for speech perception, emotion identification and melodic contour identification; identification of a 5-note melodic contour. Again normal acoustical stimuli and CI simulations were used. Results showed only a small transfer effect of musical training on speech for only the CI simulated word in noise condition. No transfer effect for speech perception was shown when listening to normal acoustical stimuli. Musicians did outperform the non-musicians for emotion identification and melodic contour identification for both normal and CI-simulated stimuli. The musician effect became more apparent as the specific task was more pitch based; so a bigger effect for melodic contour identification than for emotion identification was found. Concluding, musicians outperform non-musicians for emotion and melodic contour identification and utilize different cues, more pitch based, than non-musicians. Only a small transfer effect of music to speech perception was shown, in one CI simulated word intelligibility test. A musician effect seems to be apparent when listening to CI simulations.

The last question was if the musician effect could also be shown in real CI users. A feasibility-study with three training groups was conducted. The groups were a musical training, a music therapy, and a control group; the non-musical training. During a six-week period in total 19 CI users were trained weekly. Before and directly after the training period the CI users tested for speech perception in noise, emotion identification and melodic contour identification. Results showed a transfer effect of music therapy on emotion identification and a within domain effect of musical training on melodic contour identification. Subjectively, the CI users in the music therapy group stated that they felt better about their perceptual skills, that they recognized emotions better, and that they began to listen to music more and enjoyed music. These findings shed a possible positive light on the effect of musical training or music therapy on the perception of CI users. This might lead to the inclusion of a music based training or therapy in the rehabilitation of CI users in clinical practice.

In conclusion, this thesis showed that the subjective perception of music in CI users differs per implantee group, but is not satisfying yet. Behaviorally tested gender categorization is abnormal and the emotion identification is impaired in CI users. The musician effect showed possible positive benefits auditory perception in NH listeners. NH musicians outperformed NH non-musicians for CI simulated tasks, more so if the task was more pitch based. A musician effect was found for gender categorization, emotion identification and melodic contour identification. In CI users a possible positive effect of musical training on melodic contour identification and of music therapy on emotion identification was found. To improve the perception of speech, pitch-related speech and music tasks, music training or musical therapy seems promising for the future rehabilitation of CI users.

SAMENVATTING

Een cochleair implantaat (CI) is een chirurgisch geïmplanteerde gehoorprothese voor zeer ernstig slechthorenden, die geen baat hebben bij conventionele hoortoestellen. De meeste CI-gebruikers verstaan spraak in stilte redelijk tot goed. Andere akoestische signalen, zoals spraakverstaan in ruis of het luisteren naar muziek is voor CI-gebruikers uitdagend. Dit promotieonderzoek onderzocht de perceptie van muziek met een CI en de mogelijk positieve invloed van muzikale training op het horen met een CI. In het eerste deel van dit promotieonderzoek is de perceptie van muziek, vocale emoties en het herkennen van het geslacht van een spreker onderzocht in CI-gebruikers. Het tweede deel onderzocht de mogelijk positieve invloed van muzikale training op de waarneming van akoestische signalen, zoals muziek en spraakverstaan in ruis, in normaalhorenden (NH) en CI-gebruikers.

Het genieten van het luisteren naar en het waarnemen van muziek is voor twee groepen CI-gebruikers met vragenlijsten onderzocht. De ene groep is een typische CI-groep: de post-linguaal dove CI-gebruiker; de andere groep is een atypische CI-groep: de vroeg-dove, laat-geïmplanteerde CI-gebruiker. De vroeg-dove, laat-geïmplanteerde CI-gebruiker is ernstig slechthorend of doof geworden tijdens de taalverwerving, maar pas op latere leeftijd, na een langere periode van slechthorendheid, geïmplanteerd. Dit in tegenstelling tot de typische CI-gebruiker, de post-linguaal dove volwassene, die na de taalverwerving als volwassene doof is geworden en geïmplanteerd. De vragenlijsten lieten zien dat de post-linguaal dove CI-gebruiker minder van het geluid van muziek geniet, dan de vroeg-dove, laat-geïmplanteerde CI-gebruiker. Het geluid van muziek was suboptimaal in beide groepen. In de typische groep CI-gebruikers was een betere subjectieve waarneming van de elementen van muziek gerelateerd aan een hogere kwaliteit van leven; deze correlatie was niet aanwezig in de vroeg-dove, laat-geïmplanteerde groep. Wellicht is het verschil tussen beide groepen te verklaren door het verschil in akoestisch geheugen voor muziek. Concluderend lieten de vragenlijsten zien dat de subjectieve perceptie van muziek suboptimaal en verschillend is tussen beide groepen CI-gebruikers en dus verbeterd zou kunnen worden.

De vraag is echter of ook het daadwerkelijk luisteren naar muziek suboptimaal is in CI-gebruikers. Met andere woorden nemen CI-gebruikers ook daadwerkelijk akoestische signalen, zoals muziek, anders of slechter waar dan bijvoorbeeld NH. In dit proefschrift is het herkennen van emoties en het geslacht van een spreker op basis van alleen het geluid onderzocht. Dit zijn beiden taken gebaseerd op het herkennen van de toonhoogte, een belangrijk element van muziek. Emotieherkenning is getest met een nonsens woord, een woord zonder betekenis, dat werd uitgesproken met vier verschillende emoties. CI-gebruikers herkenden de emoties slechter dan de NH. Om na te gaan waarom CI-gebruikers de emoties slechter waarnamen, zijn verschillende akoestische parameters die emotieherkenning en nadruk in emoties kenmerken, zoals de gemiddelde toonhoogte, de range van de toonhoogtes en het aantal dominante toonhoogtes, vergeleken. Hieruit blijkt dat CI-gebruikers de range van de toonhoogte gebruiken voor emotieherkenning, terwijl NH de gemiddelde toonhoogte gebruiken. Mogelijk is de CI-gebruiker onvoldoende in staat om de gemiddelde toonhoogte waar te nemen.

In een tweede studie werd het categoriseren van het geslacht van een spreker, het differentiëren tussen man en vrouw op basis van het stemgeluid alleen, getest. Door het aanpassen van de afstand van de stemplooien tot aan de lippen (VTL) en de toonhoogte van de stem (F0) via een glijdende schaal, kan een vrouwenstem die geleidelijk overgaat in een mannenstem gesimuleerd worden. De resultaten toonden dat CI-gebruikers de vrouwen- en mannenstemmen anders categoriseerden dan NH. Geïmplanteerden gebruikten vrijwel alleen de toonhoogte om een verschil tussen sprekers waar te nemen. NH gebruikten zowel de toonhoogte als de afstand van de stemplooien tot de lippen. Wellicht wordt de VTL , de maat voor de afstand van de stemplooien tot aan de lippen, niet goed waargenomen door CI-gebruikers. De uitkomsten van beide studies tonen aan dat CI-gebruikers waarschijnlijk in het dagelijks leven problemen ervaren bij het herkennen van emoties of het geslacht van een spreker op basis van het geluid alleen. Samengevat toonden deze twee studies dat de identificatie van emoties slechter en anders is in CI-gebruikers, en dat CI-gebruikers het geslacht van een spreker anders categoriseren dan NH. Opnieuw een reden om te onderzoeken of de waarneming van deze akoestische signalen verbeterd zou kunnen worden.

Een mogelijke verbetering van de identificatie van emoties, het geslacht van een spreker of muziek zou kunnen worden gevonden in ofwel het verbeteren van het CI, via bijvoorbeeld betere bewerking en verwerking van het signaal in de processor van de CI, ofwel via het verbeteren van de CI-gebruiker zelf, via bijvoorbeeld training. In dit proefschrift hebben we onderzocht of muzikale training, het zogenoemde ‘musicus effect’, een verbetering van het horen in CI-gebruikers kan geven. Het musicus effect is het voordeel dat NH-musici hebben bij het waarnemen van bepaalde akoestische stimuli. Zo herkennen musici muziek, maar wellicht interessanter spraakverstaan in ruis beter waar dan niet-musici. De vraag is of dit musicus effect ook bestaat wanneer akoestische signalen met een CI worden waargenomen. Om antwoord te geven op deze vraag hebben we het musicus voordeel in CI-gebruikers en NH onderzocht.

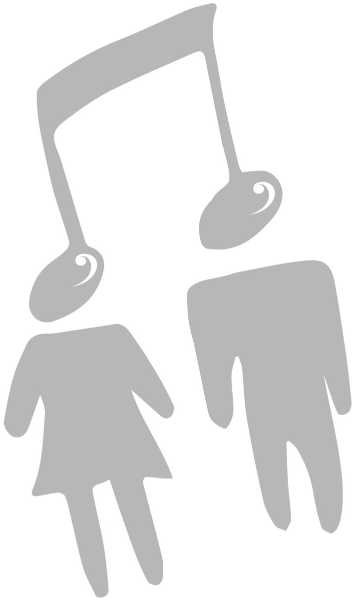
Allereerst is de muzikale training van de CI-gebruiker voor implantatie onderzocht met vragenlijsten. Vervolgens werd gekeken of er een relatie bestaat tussen deze muzikale training en het spraakverstaan en de kwaliteit van leven. CI-gebruikers blijken nauwelijks muzikale training te hebben en er werd geen correlatie aangetoond van de muzikale training met spraakverstaan en de kwaliteit van leven. Wel is het beter waarnemen van de elementen van muziek, zoals toonhoogte en timbre, gerelateerd aan een hogere kwaliteit van leven. Het musicus effect was dus niet duidelijk aanwezig in de geteste CI-gebruikers, hoewel hierbij moet worden aangemerkt dat de CI-gebruikers in onze groep nauwelijks muzikale training hadden.

Om toch te kunnen nagaan of het musicus effect bestaat voor CI's, is een experiment met NH-musici en niet-musici gedaan. In deze studie hoorden de deelnemers normale akoestische stimuli en CI-gesimuleerde stimuli. De deelnemers luisterden net als de CI-gebruikers in de eerdere studies naar emoties, naar het geslacht van een spreker, maar ook naar melodieën en naar spraak in stilte en in ruis. Musici bleken het geslacht van een spreker anders te categoriseren dan niet-musici. Musici gebruiken de toonhoogte (F0) meer dan de afstand van de stemplooien tot de lippen (VTR), terwijl niet-musici beiden gebruiken. Een interessante bevinding omdat ook CI-gebruikers (zonder muzikale training) de toonhoogte gebruikten om het geslacht te categoriseren. Wellicht wordt de afstand van de stemplooien van de lippen niet afdoende doorgegeven via het CI en is dus de toonhoogte het deel van het signaal wat het beste het geslacht categoriseert in CI-geluid. Musici herkenden emoties en melodieën beter dan niet musici voor normale signalen, maar ook voor CI-simulaties. Alle drie taken die deels afhankelijk zijn van een betere herkenning van toonhoogtes. Musici bleken echter maar in één conditie van de CI-simulaties beter in het spraakverstaan in ruis. Kortom, musici zijn ook in situaties waarin het akoestische signaal minder rijk is ofwel CI-gesimuleerd, in staat om zowel spraak gerelateerde taken, zoals emotieherkenning, als muziek beter waar te nemen dan niet-musici. Het musicus effect lijkt dus wel te bestaan bij het luisteren naar CI-simulaties en was duidelijker aanwezig naarmate de taak meer op het herkennen van de toonhoogte gebaseerd was.

Afsluiten hebben we een korte trainingsstudie met CI-gebruikers verricht om te onderzoeken muzikale training het horen verbeterd. Negentien CI-gebruikers werden verdeeld over drie trainingsgroepen: muzikale training, muziektherapie en niet-muzikale training. Individueel of in groepen hebben ze vervolgens zes weken lang, twee uur per sessie getraind. De resultaten lieten zien dat muzikale training het waarnemen van melodieën verbeterd en dat muziektherapie de emotieherkenning verbeterd. Het spraakverstaan verbeterde niet in de drie trainingsgroepen. Subjectief gaven de CI-gebruikers in de muziektherapiegroep aan dat ze meer van muziek genoten en dat ze vonden dat ze muziek beter waar konden nemen na de therapie. Hoewel moet worden aangemerkt dat dit een kleine studie was uitgevoerd binnen een kort tijdsbestek, bieden deze resultaten hoop voor het mogelijk positieve effect van muzikale training of muziektherapie op de waarneming van melodieën en emoties in CI-gebruikers.

De resultaten van dit proefschrift laten zien dat het waarnemen van muziek door CI-gebruikers kan worden verbeterd. CI-gebruikers hebben een abnormale waarneming van het geslacht van een spreker en een verminderde herkenning van emoties. In NH werd een musicus effect aangetoond luisterend naar CI-simulaties voor emotieherkenning, categorisatie van het geslacht van een spreker en het herkennen van melodieën. Het musicus effect is waarschijnlijk gebaseerd op een betere waarneming van toonhoogtes. Hoewel er tussen de subjectieve muzikale training van CI-gebruikers en de waarneming van spraak geen relatie is gevonden, zou muzikale training of muziektherapie in de revalidatie kunnen worden toegepast om het horen met een CI te optimaliseren, omdat een korte trainingsperiode al positieve resultaten liet zien. De revalidatie zou zich meer kunnen richten op het trainen van de muziek.

Dankwoord



Dit werk zou niet tot stand zijn gekomen zonder het enthousiasme, doorzettingsvermogen en de hulp van velen.

Allereerst wil ik alle CI-gebruikers, musici en niet-musici die aan de studies hebben meegewerkt van harte danken. Zonder het enthousiasme van alle deelnemers zou de wereld niet een klein beetje wijzer zijn geworden. Het was een feest om zowel in de stille kamer, de faculteit, als in het voormalig CI-huis in Haren met een ieder van jullie te mogen samenwerken. Het was een fantastisch project. Hopelijk krijgt het een waardig vervolg!

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CURRICULUM VITAE

Christina Fuller werd geboren op 2 juni 1985 in het Drentse Borger. Na afronding van het gymnasium aan het *Esdal College* in Emmen, startte ze in 2003 de studie Nederlandse taal en cultuur aan de *Rijksuniversiteit Groningen*. In 2004 begon ze hiernaast aan de studie geneeskunde aan dezelfde universiteit. Na het afronden van haar studie Nederlands in 2008 met de master thesis 'De inleidende gedichten van Jacob Cats voor Johan van Beverwijck in het eerste deel van de Schat der Gesontheyt', startte zij haar co-schappen, in het *Universitair Medisch Centrum Groningen* en het *Deventer Ziekenhuis*. In 2011 rondde zij de studie geneeskunde succesvol af, nadat zij zich in het laatste jaar van de studie had gericht op de keel-, neus- en oorheelkunde. Haar master thesis richtte zich reeds op de muziekbeleving en de kwaliteit van leven van cochleair implantaat gebruikers. Aansluitend startte zij haar promotietraject in 2011 op de afdeling KNO van het UMCG onder de leiding van prof. dr D. Başkent, dr. R.H. Free en prof. dr. B.F.A.M. van der Laan. Vanaf november 2013 is zij in opleiding tot keel-, neus- en oorarts in het UMCG met als opleider prof. dr. B.F.A.M. van der Laan en in het Medisch Centrum Leeuwarden onder dr. H. van den Berge.