MUSIC PERCEPTION OF COCHLEAR IMPLANT RECIPIENTS USING A GENETIC ALGORITHM MAP

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ABSTRACT

Cochlear implant (CI) users have traditionally reported less enjoyment and have performed more poorly on tasks of music perception (timbre, melody and pitch) than their normal hearing (NH) counterparts. The enjoyment and perception of music can be affected by the MAP programmed into a user's speech processor, the parameters of which can be altered to change the way that a CI recipient hears sound. However, finding the optimal MAP can prove challenging to clinicians because altering one parameter will affect others.

Until recently the only way to find the optimal MAP has theoretically been to present each potential combination of parameters systematically, however this is impractical in a clinical setting due to the thousands of different potential combinations. Thus, in general, clinicians can find a good MAP, but not necessarily the best one. The goal of this study was to assess whether a Genetic Algorithm would assist clinicians to create a better MAP for music listening than current methods.

Seven adult Nucleus Freedom CI users were assessed on tasks of timbre identification, melody identification and pitch-ranking using their original MAP. The participants then used the GA software to create an individualised MAP for music listening (referred to as their "GA MAP"). They then spent four weeks comparing their GA and original MAPs in their everyday life, and recording their listening experiences in a listening diary. At the end of this period participants were assessed on the same timbre, melody, and pitch tasks using their GA MAP.

The results of the study showed that the GA process took an average of 35 minutes (range: 13-72 minutes) to create a MAP for music listening. As a group, participants reported the GA MAP to be slightly better than their original MAP for music listening, and preferred the GA MAP when at the cinema. Participants, on average, also performed significantly better on the melody identification task with their GA MAP; however they were significantly better on the half-octave interval pitch ranking task with their original MAP. The results also showed that participants were significantly more accurate on the single-instrument identification task than the ensemble instrument identification task regardless of which MAP they used. Overall, the results show that a GA can be used to successfully create a MAP for music listening, with two participants creating a MAP that they decided to keep at the conclusion of the study.

1. INTRODUCTION

1-1. NORMAL HEARING

The human ear can be divided into three areas: the outer, middle and inner ears. As shown in Figure 1, the outer ear consists of the pinna and ear canal. The middle ear includes the ear drum and the ossicles (malleus, incus and stapes). Finally, the inner ear is used to describe the portion of the ear that includes that cochlea and the auditory nerve.

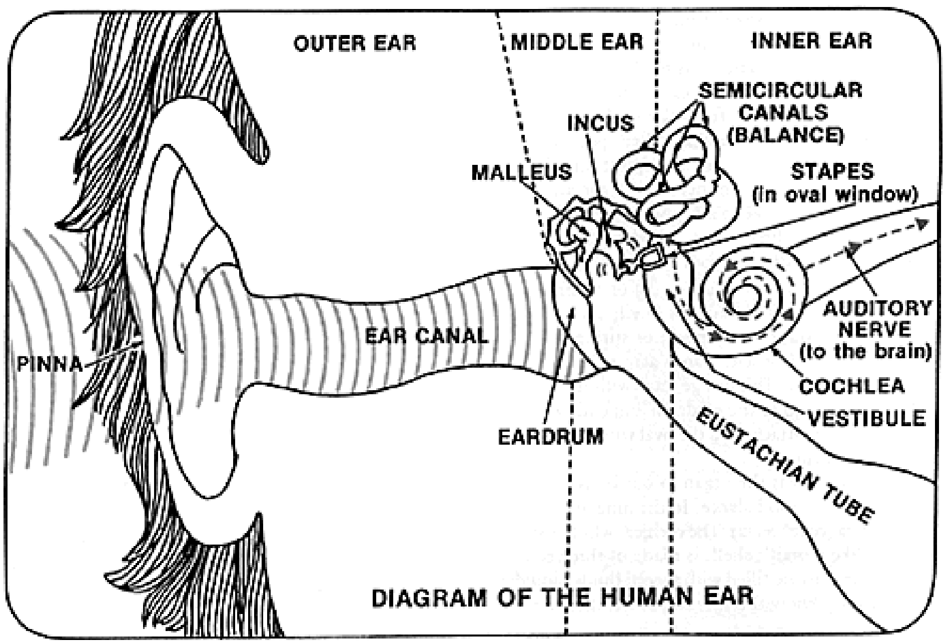

Figure 1: The pathway of sound in the human hearing system (Laurent Clerc Center)

The cochlea (organ of hearing) is located in the temporal bone of the skull. It is a 30mm long bony tube arranged in a spiral shape. Inside the bony exterior, the cochlea is separated into three fluid-filled compartments, as shown in Figure 2: scala tympani, scala media, and scala vestibuli. These compartments are separated by two membranes: Reissner's membrane and the Basilar Membrane (BM).

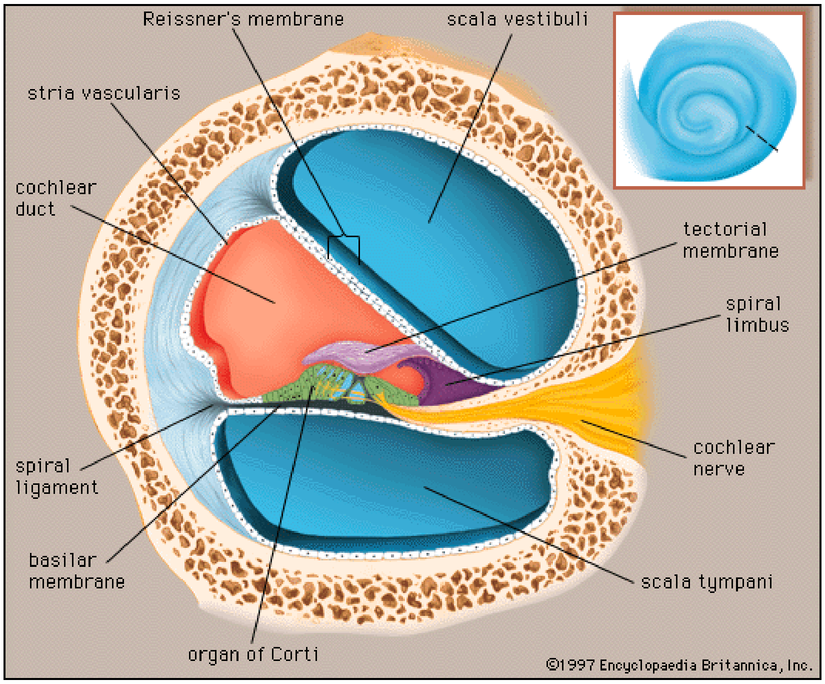

Figure 2: Cross-section of the cochlea (Encyclopaedia Britannica, 2010)

The BM travels the length of the cochlea and is wider and less stiff at the apex than at the base. This change in physical property along the length of the cochlea means that different areas of the membrane respond better to different frequencies, with the base responding maximally to high frequencies, and the apex responding maximally to low frequencies. This is referred to the tonotopic organisation of the cochlea. See Figure 3.

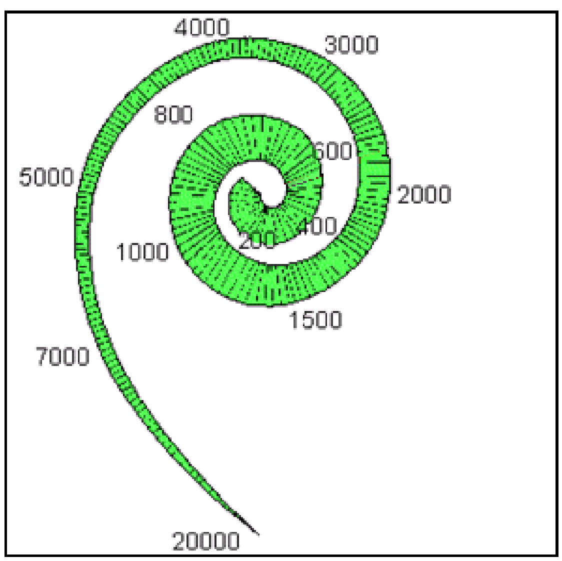

Figure 3: The tonotopic organisation of the cochlea (Port, 2007)
The numbers represent the frequencies (Hz) to which the Basilar Membrane maximally responds.

Located on top of the Basilar Membrane is the Organ of Corti which contains the inner and outer hair cells, see Figure 4. The outer hair cells are arranged in three to five rows, and atop each cell are stereocilia which connect to the Tectorial Membrane (TM). These stereocilia move in response to the changing positions of the BM and TM. The inner hair cells, by contrast, are arranged in a single row and their stereocilia are not attached to the TM.

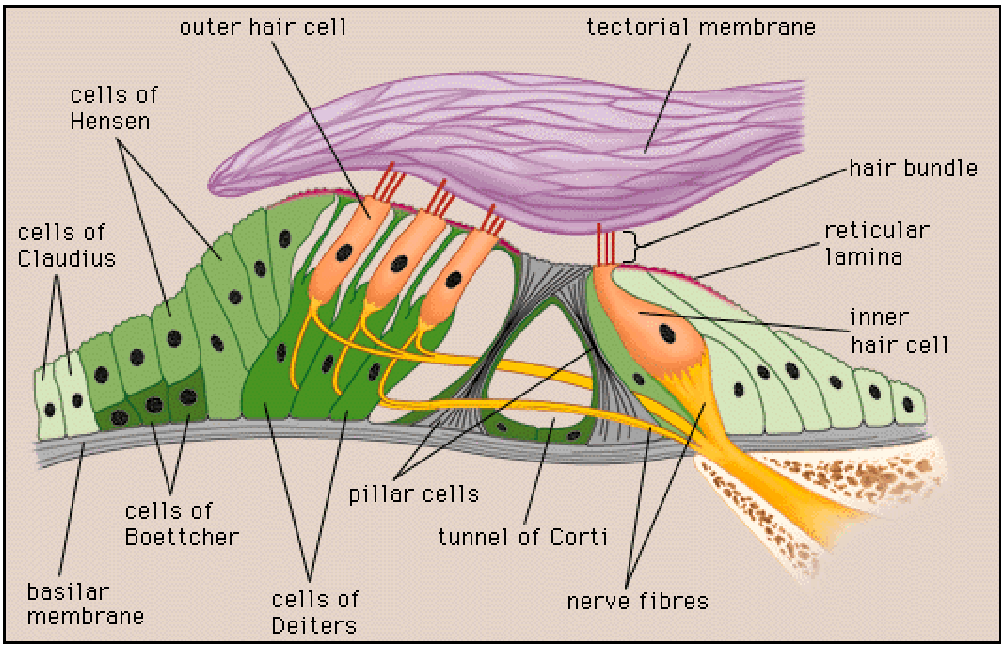

Figure 4: Anatomy of the Organ of Corti (Encyclopaedia Britannica, 2010)

As shown in Figure 1, in normal hearing (NH), sound waves are collected by the pinna and directed down the external auditory canal to the tympanic membrane (eardrum). The sound waves cause the eardrum to vibrate, and this vibration travels along the ossicles to move the footplate of the stapes in and out of the oval window. This movement transfers the energy of the sound waves from the eardrum to the inner ear, creating a travelling wave along the length of the Basilar Membrane (BM). The wave travels rapidly from the base of the cochlea, growing in size and speed until it reaches its place of resonance, the point along the BM which responds maximally to the frequency of the incoming sound. At this point, the BM vibration causes the outer hair cell stereocilia to bend medially and laterally which is thought to act as an amplifier to increase the response of the inner hair cells. While the outer hair cells are thought to act as an amplifier, the inner hair cells are considered to be responsible for turning mechanical vibrations into neural activity (Moore, 2003). The vibration of the inner hair cell stereocilia results in a flow of current and the release of neurotransmitter onto the auditory nerve. The auditory nerve then carries the electrical representation of the sound up the ascending auditory pathway to the auditory cortex in the brain.

The above describes the process for a NH individual, however impairment along this pathway can cause a hearing loss. If the impairment occurs in the inner ear, then this is called a sensorineural hearing loss (SNHL). SNHL is the result of damaged, or absent, hair cells and affects the way sound is processed in the cochlea. The impairment is classified in terms of the degree of hearing loss and ranges from a mild impairment to a profound hearing loss. The intervention for SNHL is usually hearing aids (HAs). However in severe to profound hearing losses, where most of the inner hair cells are damaged or absent, an individual will not receive sufficient amplification from a HA to significantly improve their speech perception. In these cases a cochlear implant (CI) may be more effective as it bypasses the hair cells to directly stimulate the auditory nerve.

1-1-1. Current New Zealand Selection Criteria for a CI

The current selection criteria for the Southern Cochlear Implant Program for Adults (SCIP-A) in New Zealand states that an adult must have:

- A severe to profound bilateral SNHL at 2 kHz or above or a deteriorating moderate to severe sloping SNHL;
- Aided (auditory alone) speech scores of less than 60% in the better ear and less than 40% in the poorer ear, or less than 50% binaurally;
- No medical/radiological contraindications to surgery and rehabilitation;
- Appropriate expectations and an understanding of the limitations associated with being a CI user.

1-2. Cochlear Implants

A CI consists of externally worn components, and a surgically implanted package. As shown in Figure 5, the external components consist of a microphone, speech processor and radio frequency transmitter, while the internal package, shown in Figure 6, consists of an electrode array and receiver-stimulator. The internal and external components are connected by a magnet, with radio-frequency waves being used to transmit the signal across the patient's skin. Figure 7 shows a diagram of the internal and external components in place.

Figure 5: External components of a cochlear implant (New Zealand Audiological Society, 2010)

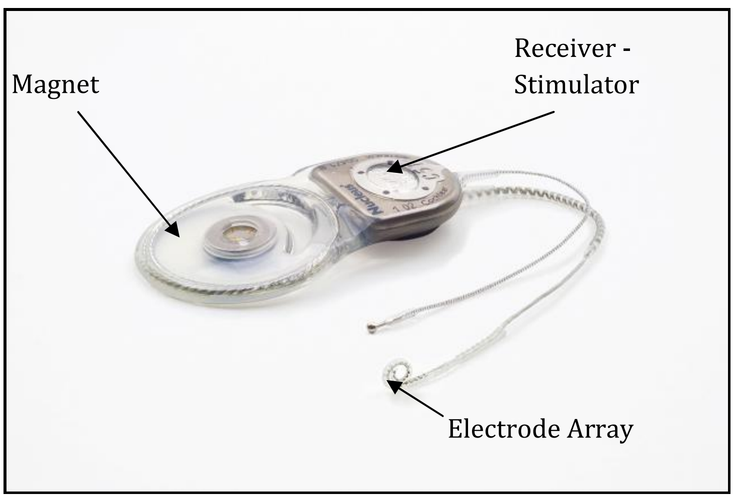

Figure 6: Internal package of a cochlear implant (New Zealand Audiological Society, 2010)

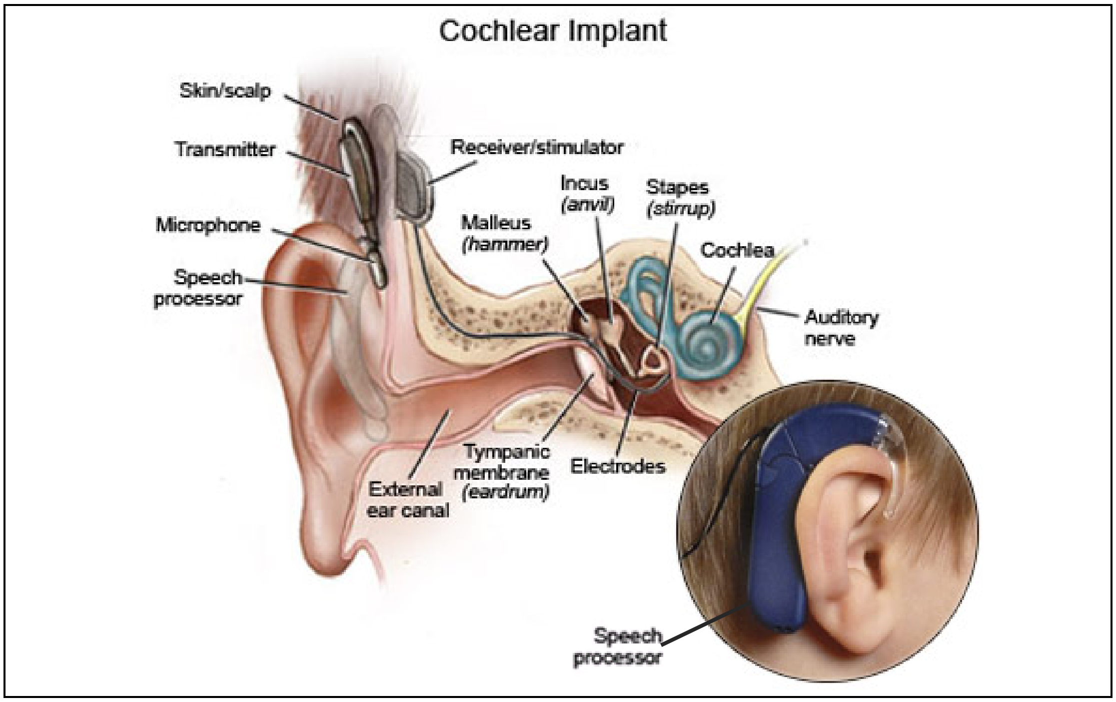

Figure 7: Diagram of the full cochlear implant system (Mayo Clinic)

Sound is picked up by the microphone which converts the incoming acoustic signals into electrical signals. This is then sent to the speech processor which converts the signal into electrical pulses based on the speech processing strategy. This information is passed across the skin from the external package's transmitter coil to the internal receiver-stimulator package which deciphers the coded signal and sends electrical pulses to the electrode array. The electrodes are then stimulated in an orderly manner, depending on the parameters of the speech processing strategy, which in turn stimulates the auditory nerve.

The speech processing strategy is central to determining the sound perceived through a CI. There are several main speech processing strategies used in modern CIs (e.g. Continuous Interleaved Sampling (CIS) and Fine Structure Processing (FSP)), however this discussion will focus on the one relevant to the current study, the Advanced Combination Encoder (ACE) strategy. ACE is an 'n-of-m' strategy that aims to provide the implant user with both spectral and temporal cues. As shown in Figure 8, it works by analysing the incoming signal and separating it into 'm' filterbands (typically 22) covering a frequency range of 188Hz to 7938 Hz (Vandali et al., 2000). The envelope of the signal for each band is compared and 'n' bands with the largest amplitudes are selected; these are known as maxima. The electrodes corresponding to the selected bands are then stimulated.

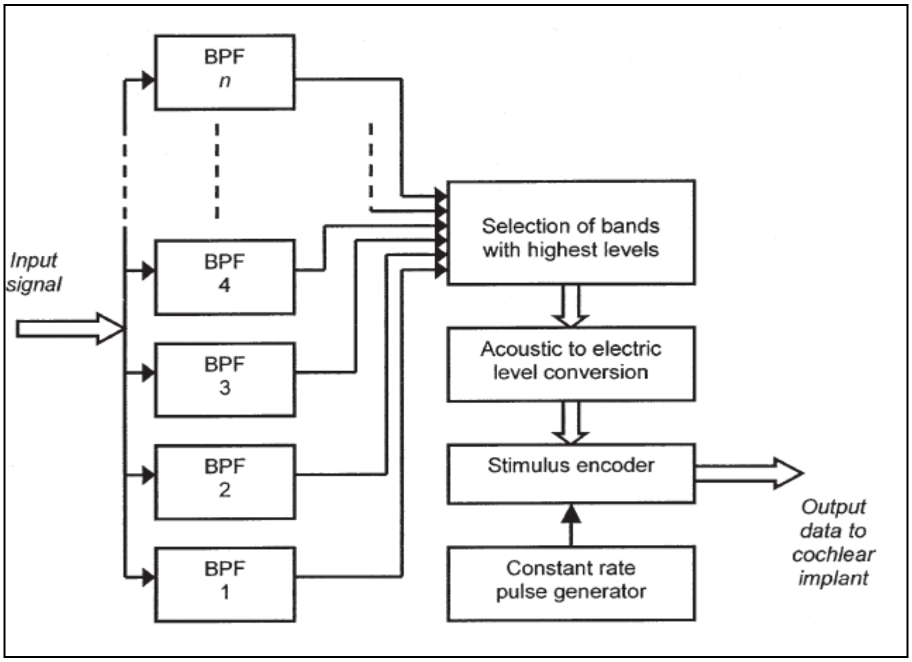

Figure 8: Diagram of the Advanced Combination Encoder (ACE) speech processing strategy (McDermott, 2004)

Despite using the same device and strategy, individuals may perceive the same acoustic stimulus differently due to auditory nerve stimulation being dependent upon the MAP programmed into the speech processor. A MAP is the set of parameters that determine the properties of electrode stimulation. These include the number of channels available for stimulation; the number of maxima (i.e. how many channels are stimulated in each cycle); the filterbank spacing (i.e. the width of the band-pass filters that the incoming sound is divided into); the stimulation rate (i.e. how fast the electrodes are stimulated in each cycle); threshold (T) levels (i.e. the minimum amount of current required for an implant user to perceive sound); and comfort (C) levels, which is the maximum amount of current before an audible sound becomes uncomfortable. All of these MAP parameters can be varied to change a user's perception of sound. For example, Boyd (2010) compared the speech perception scores of 12 post-lingually deafened adult MED-EL COMBI 40+ recipients when using their original MAP and a flat MAP (i.e. a MAP where the Most Comfortable Loudness levels were the same for all channels). Boyd reported that subjective preference of the MAPs varied, with some participants reporting the two MAPs to sound similar, while others reported the flat MAP to sound strange, indicating that a CI user's perception of sound can be varied by changing just one MAP parameter.

When setting a MAP, it is the audiologist's task to select the parameters that are the best for the individual implant user. However, no one MAP works well for every CI user due to the distinctive needs of different individuals (Skinner, 2003). In the Boyd (2010) study, he compared the speech perception scores of the 12 CI users when using their original MAP and the generic simplified MAP. The results showed that speech discrimination was significantly poorer for the simplified MAP (60.5%) than for the original customised MAP (72.7%). The results from the Boyd (2010) study demonstrates the need for a customised MAP for CI recipients, however this presents a challenge to clinicians because the parameters can be assembled into over a thousand different combinations. Furthermore, parameters cannot be adjusted one at a time, as in traditional optimisation methods, as altering one parameter tends to affect another. It is therefore clinically impractical to present each possible combination of parameters to an individual in order to select the optimal MAP, and while clinicians can generally fit a good MAP, it may not be the optimal MAP for that individual (Lineaweaver, 2007).

In general, research has demonstrated that most current recipients achieve excellent speech perception in quiet with current commercially available speech processing strategies. In one study, ninety-six adult recipients tested on the City University of New York (CUNY) sentences scored an average of 82.1% correct when the CUNY sentences were presented at 70 dB SPL in quiet (Fetterman & Domico, 2002). However, for more complex stimuli such as music or speech in noise, performance of CI users is significantly poorer (Balkany et al., 2007; Fetterman & Domico, 2002; Firszt et al., 2004; see McDermott, 2004 for a review of music). Given that CI users perform poorer with music than speech in quiet, and that music significantly impacts on CI users' quality of life (Zhao et al., 2008), it is important that researchers investigate methods of improving music perception.

1-3. Music Perception of CI Users

Music can be split into four major elements: rhythm, pitch, melody and timbre (Drennan & Rubinstein, 2008). Individual variability in the perception of music not only depends on the ability to perceive these four elements, but is also impacted on by culture, age, listening preferences, and experience or training with music (Looi, 2008). Current research provides evidence that while CI users are able to perceive broad temporal cues associated with rhythm, they tend to struggle with perceiving spectral cues related to pitch, melody and timbre.

1-3-1. Rhythm

Rhythm refers to the slow varying temporal patterns in musical sounds (McDermott, 2004). Evidence has shown that CI users perform similarly to NH individuals on tasks of rhythm perception. As part of a study by Gfeller et al. (1997), 35 NH adults and 17 CI recipients using the now superseded F0F1F2 and MPEAK strategies were compared on a modified Primary Measures of

Musical Audiation (PMMA) test. They found that there was no significant difference between the scores of the NH and CI groups on the rhythmic subtest. One possible reason for this better performance on tasks relating to rhythm is that broad temporal cues would be more saliently transmitted by CI systems than pitch-based cues (McDermott, 2004).

1-3-2. PITCH

Pitch for a pure tone is closely related to the pure tone's frequency (Moore, 2003), however for complex sounds, such as music and speech, the pitch is associated with the fundamental frequency, and/or interval between the harmonics of the signal (Allen, 2007). In NH individuals, pitch is currently thought to be encoded by both place-pitch and temporal pitch cues (Moore, 2003). For NH listeners, place-pitch cues result from the travelling wave and the tonotopic organisation of the cochlea. As the travelling wave moves along the BM, it grows in size and velocity until it reaches the place of resonance, which is the site of maximum displacement, and is related to the pitch of the fundamental frequency of the acoustic stimulus (Moore, 2003). For frequencies less than 5000 Hz, the neural firing in the cochlea occurs at a rate close to the frequency of the stimulus. This phase-locking of the neural firing is the basis of temporal-pitch cues (Moore, 2003).

However, CI users generally have more difficulty perceiving and/or using these cues and consequently their pitch perception is typically poorer than that of NH individuals (e.g. Gfeller, Turner et al., 2002). In implant users, place-pitch cues are conveyed with changes in the place of stimulation (i.e. which electrode is stimulated), while temporal cues are perceived by either modulating the amplitude or changing the rate of the stimulating pulse train (McDermott, 2004). However, as the ACE strategy uses a constant rate pulse train, the only temporal cues available to users of this strategy are via amplitude modulations. Further, the salience of these cues to CI users can be affected by a number of factors. These include poor frequency selectivity, mismatch between the frequency assigned to an electrode and the region of the BM excited by that electrode, distance separating active electrodes, fixed rates of stimulation, an absence of fine-structure information, and biological limitations (Looi, 2008).

Current speech processing strategies (including ACE) use a filterbank approach modelled on the filtering properties of the BM. However, the filters in the implant are fewer in number and wider than those in the NH cochlea; this affects the specificity of their frequency resolution. The frequency components of a complex sound are less likely to be fully resolved for CI users than for NH individuals. Further, for components that are resolved, the implant user may not be able to determine the exact frequency of the resolved component as the electrode associated with the filter band stimulates a large population of auditory neurons.

Implant users also experience difficulty perceiving pitch due to the frequency-mismatch between the place of stimulation and the corresponding place of resonance of the cochlea. The electrode array of an implant is generally inserted 1.5 turns into the cochlea (see Figure 9), meaning that more apical regions of the cochlea are not stimulated. As a consequence, an electrode stimulates an area of the cochlea that is typically higher than the frequency band assigned to that electrode. Nardo et al. (2007) assessed five adult Nucleus CI24R users on their ability to match electric pitch with the pitch of a pure-tone presented via their residual hearing. Results demonstrated the pitch sensations for apical electrodes were 1-2 octaves higher than expected, and that this mismatch tapered off as the electrodes became more basal.

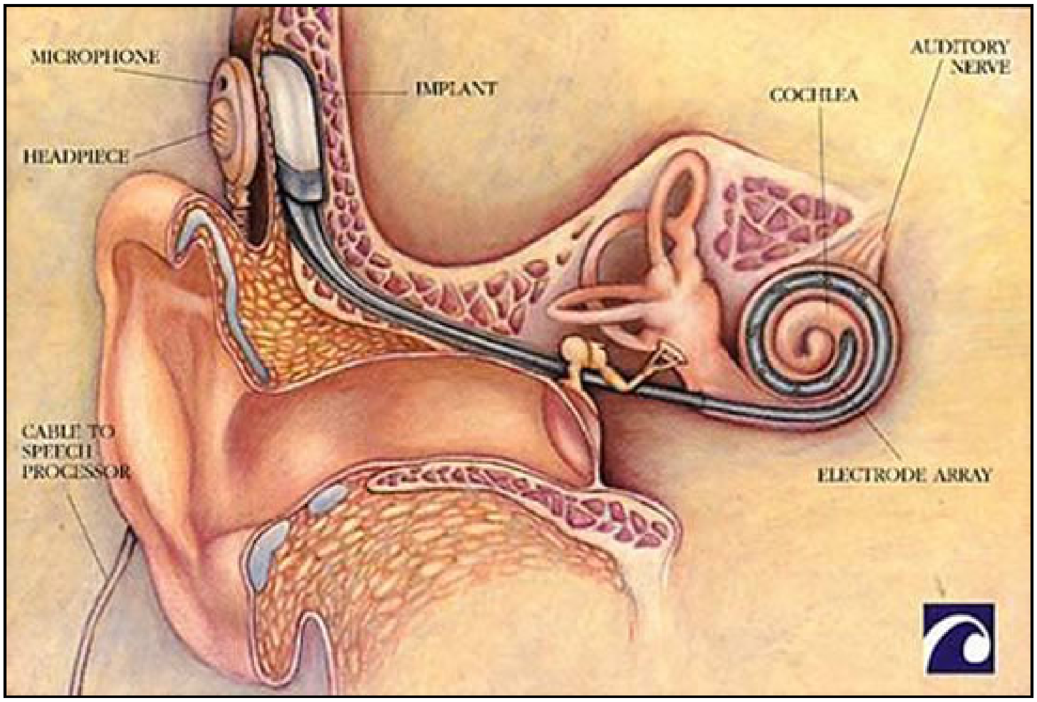

Figure 9: Diagram showing the insertion depth of a typical electrode array (1.5 turns) (Scottish Cochlear Implant Programme, 2008)

Multi-channel CIs are based on the principal that different electrodes activate independent populations of auditory neurons. However, the poor spatial separation between electrodes in the cochlea may lead to issues with place-pitch cues. Complex sounds, like music, contain many components and frequencies which stimulate multiple electrodes. This can cause problems if the activated electrodes are adjacent to one another as longitudinal current spread may excite large numbers of auditory neurons, meaning that individual electrodes do not stimulate independent populations of auditory neurons, thus impairing a recipient's ability to make accurate use of place-pitch cues (e.g. Townshend et al., 1987). Tong and Clark (1985) looked at the effect of spatial separation on the ability of seven Nucleus CI users, with a 22 electrode array, to identify the position of a stimulated electrode when stimulated with 200-ms steady-state pulse trains. They found that as the spatial separation between activated electrode pairs increased, so did perceptual sensitivity.

The ACE processing strategy only preserves envelope information, omitting the fine structure information. In pitch perception, the fine structure information is important for resolving the individual frequency components of the signal, and the omission of the fine structure hinders the ability of a CI user to resolve the harmonics of a complex tone. The importance of fine structure to pitch perception is evidenced in a study by Kong et al., (2005). Five postlingually deafened CI users with a hearing aid in the contralateral ear were assessed on their ability to perceive the pitch cues required for melody recognition. Participants were tested with their HA alone, CI alone and CI with HA. The results showed that, on average, participants were more accurate with their HA than with CI alone (by 17 percentage points). The authors postulated that this was due to the additional low-frequency fine-structure information that is available with acoustic, as opposed to electric hearing. Furthermore, the performance with HA alone and CI with HA were found to be similar.

Finally, evidence has shown that biological limitations associated with a cochlear hearing loss impacts on frequency resolution and hence decreases pitch perception abilities. Pick et al. (1977) reported that individuals with hearing thresholds between 40-50 dB HL had auditory filter bandwidths approximately twice the width of their NH counterparts. The consequence of having this broader bandwidth is a reduced ability to resolve the frequency components of a complex sound. The implication of this is that even if a CI was able to accurately present place- and temporal-pitch cues to CI users, the wide auditory filters would mean that their ability to use this information is poorer than for NH individuals.

With the above considerations taken into account, it is accepted that CI users generally perform poorly on tasks that involve pitch perception. As part of their 2007 study, Gfeller et al., investigated the accuracy of 101 long-electrode CI users and 21 NH adults on a pitch ranking task. Participants were required to determine the direction of pitch change for a pair of pure tones ranging from 131 Hz to 1048 Hz, and with interval sizes of 1, 2, 3, or 4 semitones. The results showed that the NH group was significantly more accurate on the task ($p<0.0001$).

Sucher & McDermott (2007) took this one step further by investigating the ability of 5 CI users and 10 NH participants to rank the pitch of complex tone pairs. Participants were required to listen to pairs of male and female sung vowels (/a/ and /i/) that differed by one semitone, and judge which they perceived as higher in pitch. The results showed that NH participants were significantly more accurate (81.2%) than the CI users (49.0%), with the CI users performing at chance level. In a second part of the same experiment, 6 NH listeners and 8 implant users performed the same task, with a six semitone interval between the two sung vowels. Again, the results showed that NH participants were significantly more accurate (89.0%) than the CI users (60.2%).

The improved discrimination abilities of CI users with increased interval size as seen in Sucher & McDermott's (2007) study is consistent with previous studies. As a part of their study Gfeller, Turner et al. (2002) investigated the difference limen for 46 CI users and 8 NH adults. The stimuli were 2 one-second presentations of a synthesised acoustic grand piano that were separated by an interval size from 1 to 36 semitones, and the participants were asked to pitch-rank the two tones. If participants were correct, the interval size was decreased, and if they were not then the interval size was increased until a threshold was obtained. The results showed that the NH group had a lower minimum threshold (1.13 semitones, range: 1-2) than the CI group (7.56 semitones, range: 1-24). It is important to note that while, as a group, the CI group required a larger interval size for accurate pitch, some CI users performed equivalently to those in the NH group. This variability in pitch perception skills of CI users is consistent with the findings of other studies (Looi et al., 2008; Nimmons et al., 2008; Sucher & McDermott, 2007).

While CI recipients perform significantly more poorly than NH listeners on pitch tasks, they also perform poorly in comparison to HA users. A study by Looi et al. (2008) assessed the pitch ranking abilities of 15 Nucleus CI users, and 15 postlingually deafened HA users. The task was similar to that used by Sucher and McDermott (2007) except that the interval sizes were one-octave, a half-octave and a quarter-octave. Looi et al. found that for all three interval sizes the CI group was significantly less accurate (68.0%, 64.3%, 51.8% respectively) than the HA group (90.2%, 83.72%, 74.7%). Furthermore, they found that the CI group's score for the quarter-octave interval was not significantly different to chance performance ($p=0.238$).

1-3-3. Melody

Melody is a pattern of pitches that are grouped together in a meaningful manner (Looi, 2008). The ability to recognise, and distinguish between, different melodies depends partly on the ability to discriminate between different pitch contours (i.e. the relative difference between adjacent pitches) as well as the ability to perceive rhythm (McDermott, 2004). Given the above problems associated with pitch perception for CI users, it is expected that implant users would find melody perception tasks more problematic than NH listeners.

Gfeller et al. (2005) compared the abilities of 79 CI users and 30 NH subjects on a familiar melody recognition task encompassing three genres: pop, classical, and country. The pop and country excerpts contained lyrics, while the classical excerpts were limited to instrumental selections. As expected, the NH group scored significantly better (54.7% correct) than the CI group (15.6% correct). They also found that CI users identified significantly fewer classical excerpts than country ($p<0.01$) and pop ($p<0.05$) excerpts, leading the authors to conclude that users relied on lyrics when identifying these melodies.

A study by Leal et al. (2003) also found that contextual cues, such as lyrics, aid melody perception. In their study, 29 Nucleus CI24 users were asked to identify songs that were presented from a list of 7-8 that they had earlier identified as being familiar. They found that 28 users were able to identify at least 50% of the songs when they were presented by an orchestra with lyrics. This was significantly higher than the number of participants who could identify at least 50% of songs when they were presented by the piano alone (14), or when the songs were presented by an orchestra without lyrics (1).

In addition to the contribution of lyrics in identifying melodies, Kong et al. (2004) demonstrated the usefulness of rhythmic cues for melody recognition for six CI users and six NH individuals. In their study, participants were required to identify 'familiar' melodies, with and without rhythm cues, from a closed-set of 12 choices. The results showed that the NH group performed similarly with and without rhythm cues (present: 93.8% correct, absent: 97.5% correct) whereas the CI group performed significantly poorer when rhythm cues were omitted (present: 63.2% correct, absent: 11.7% correct), with their performance being at levels close to chance (8%) when no rhythm cues were present. Thus, while NH listeners can usually identify melodies regardless of the presence of rhythm cues, CI users seemingly rely on rhythm cues to identify melody.

1-3-4. TIMBRE

The Acoustical Society of America (1960) (cited in Gfeller, Witt, Adamek et al., 2002) defines timbre as "that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar". Timbre is particularly important for the discrimination between different musical instruments, sound quality, and for aesthetic enjoyment (Gfeller et al., 1998). For NH individuals the perception of timbre depends on both the spectral and temporal information contained in the sound (Handel, 1989), however for CI users the salience of this information can be diminished, impacting on timbre perception. As the frequency spectrum and amplitude envelope of a sound are the principal properties of timbre (McDermott, 2004), the perception of timbre by NH listeners depends on both the cochlea's ability to resolve frequency components of the sound into different auditory filters, and the excitation pattern (i.e. size of the response for each filter in the cochlea) (Moore, 2003). For NH individuals, timbre is encoded by both temporal and place coding, similar to pitch. Consequently, the aforementioned issues affecting pitch perception for CI recipients (e.g. reduced place coding ability, lack of temporal fine structure information, difficulty resolving spectral components, larger filter bandwidths) will also affect their timbre perception (see McDermott, 2004; or Moore, 2003 for a review).

In particular, the poor frequency resolution inherent to current implants results in spectral smearing. Spectral smearing partly results from the broad auditory filters that exist in contemporary CIs. The effect of spectral smearing on timbre perception can be seen in Liu & Fu (2007) who assessed four NH individuals on their ability to recognise vowels when presented through a simulation of a 4-channel processor. The vowels were presented in four different conditions of spectral smearing. These were simulated by varying the amount of spectral overlap between adjacent carrier bands in 4-channel processors. The results showed that participants were able to recognise significantly more vowels with less spectral smearing ($p<0.001$).

Gfeller, Witt, Woodworth et al. (2002) found a significant difference between NH individuals and CI users on a task that required them to identify musical instruments. Fifty-one CI users and 20 NH listeners were presented with a seven-note sequence of equal-duration notes played by eight different musical instruments. Participants had to identify which instrument they heard from a closed set of 16 items. They found that, on average, the NH group identified significantly more instruments (90.9%; range 67-100%) correct than the CI group (46.55%; range 11-100%). However, whereas the NH group often confused instruments from within the same family (e.g. violin with cello), the CI group had no regular pattern of confusion and often mistook instruments from different families (e.g. violin and flute).

Gfeller et al. (1998) compared the abilities of 28 CI users and 41 NH listeners in their ratings of sound quality of instrumental sounds. Participants were presented with melodic patterns played by one of four instruments, and they had to rate the pleasantness of the sound they had heard on a 100 mm visual analog scale from "dislike very much" (0mm) to "like very much" (100mm). The results showed that the NH group appraised the instruments as significantly more pleasant (57.03) than the CI users (47.31). Overall these studies demonstrate that CI users are significantly poorer on tasks of timbre identification and appraisal.

1-4. MUSIC APPRECIATION

While pitch, melody, timbre and rhythm are important for perceiving music, these elements do not define the music listening experience. Music listening, particularly enjoyment, is not necessarily just related to the perceptual abilities of CI users. Instead it involves a variety of factors including emotion, context, memory, culture and personal preference (DeNora, 2000). For example, two people may listen to the same piece of music, which they have identified correctly, but report different levels of enjoyment. As such, music appreciation and perceptual accuracy are two separate issues.

In contemporary society, music is a common occurrence and has many uses (North, 2004). For example DeNora (2000) talks about music in relation how it shapes the individual's perception of themselves, and Sloboda (2005) proposes that music is used as a catalyst for change in listener's lives. Further, in a survey of 500 elderly individuals, Laukka (2007) demonstrated that the purpose for music listening was significantly correlated with psychological well-being.

Given that music can be listened to for recreational, emotional, and social purposes, it is not surprising that a decrease in music enjoyment may negatively impact on an individual's Quality of Life (QoL). Zhao et al. (2008) demonstrated the importance of music enjoyment to QoL in 24 CI recipients. They had participants identify the aspects of their life that had been impacted by hearing loss and the effect their hearing loss had on their QoL. The results showed that, for half of the respondents, their enjoyment of music had been affected by their hearing loss and that music enjoyment was a significant determinant of QoL. Hence strategies or research that leads to improved music enjoyment are important for QoL.

Research has demonstrated that CI users generally report lower levels of enjoyment from music listening than their NH peers. Mizra et al. (2003) had 35 CI users rate aspects of their music listening habits and enjoyment pre-deafness and post-implantation. While most individuals listened to music prior to their hearing loss, only 46% continued to do so after implantation. In addition, pre-deafness music enjoyment was given a mean score of 8.7 out of 10, and post-implantation this dropped to 2.6. Even for the 16 users who still listened to music, the mean enjoyment score post-CI was significantly less (5.6). This result is consistent with other studies (e.g. Gfeller, Christ et al., 2000; Lassaletta et al., 2008; Migirov et al., 2009).

The above study, however, does not investigate the period of time between when an individual had normal hearing and when they were implanted. A study by Leek et al. (2008) investigated the effect of having a hearing loss on the music listening experiences of 68 elderly HA users. They found that 28% of participants felt their hearing loss had affected their enjoyment of music. This result indicates that poor levels of music appreciation may not just be due to the implant itself, but also result from factors related to having a hearing loss. A study by Looi et al. (2007) appears to confirm this. Looi et al. (2007) compared the quality ratings of music for 15 CI users and 15 HA users, as well as for nine individuals who were on the waiting list for a CI, pre-implant and post-CI switch-on. Participants listened to five-second extracts of music played by twelve different instruments/ensembles divided into three categories: a) single instrument, b) solo instrument accompanied by an orchestra, and c) music ensembles. For each presentation the participant was told which of the 12 different instruments/ensembles they had heard and were asked to rate the pleasantness. They found that the HA group generally gave lower ratings than the CI group, although this result was not statistically significant. For the nine participants who were tested pre- and post-implantation, the results showed that the post-switch-on ratings were significantly higher than the pre-implant ratings (whilst listening with HAs). This result suggests that even though listening to music through a CI is less pleasant than listening to music with NH, it is an improvement on listening to music through a HA. Subsequently, it also suggests that the barrier to music appreciation is at least in part due to biological factors associated with the hearing loss. If this is the case, then perceptual accuracy equivalent to a NH listener may not be a realistic expectation for a CI recipient, however maximising their current device and MAPs to provide the best music listening potential would be critical.

1-5. Genetic Algorithm

The Genetic Algorithm (GA) was originally presented by John Holland (1962), and is based on the biological principles of evolution and survival of the fittest. It is a method used to search a large number of potential solutions when the solutions consist of multiple factors ("genes"). In a GA, potential solutions that contain genes that do not help answer the problem are eliminated, and the remaining genes are recombined in the hope that a better solution will emerge (Jones, 2005). The GA process can be broken into four steps, as illustrated in Figure 10. The generation of the initial set of solutions (initialisation) occurs once, but the remaining three steps will repeat until a solution is met. For the purpose of this thesis, the principles of the GA will be discussed in terms of their application to this study and, more specifically, how they relate to the creation of a CI MAP for music listening. In this application, the possible solutions are the MAPs, and the genes are the MAP parameters.

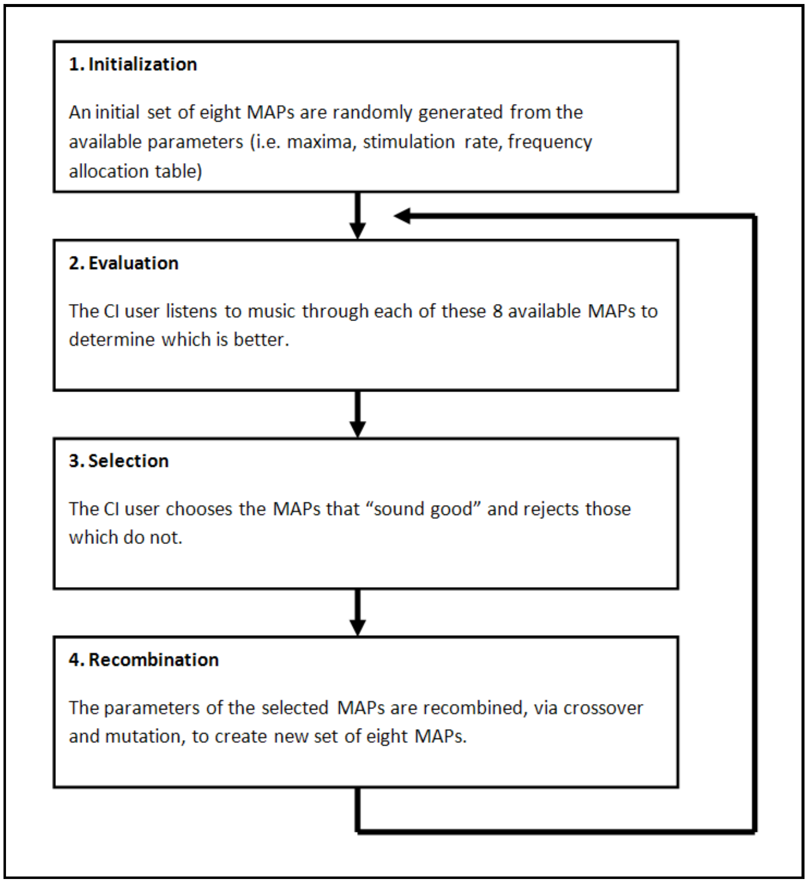

Figure 10: The genetic algorithm process for creating a music MAP (adapted from Jones, 2005)

At the beginning of the process (initialisation), a preliminary set of eight MAPs are randomly generated from the available genes (i.e. maxima, stimulation rate, and frequency allocation table). The screen seen by the user is shown in Figure 11. The CI user then listens to each of these MAPs to determine which is better for listening to music (evaluation). The listener then chooses the MAPs that "sound good" (i.e. does a good job of solving the problem); thereby rejecting those which do not help (selection) (see Figure 12).

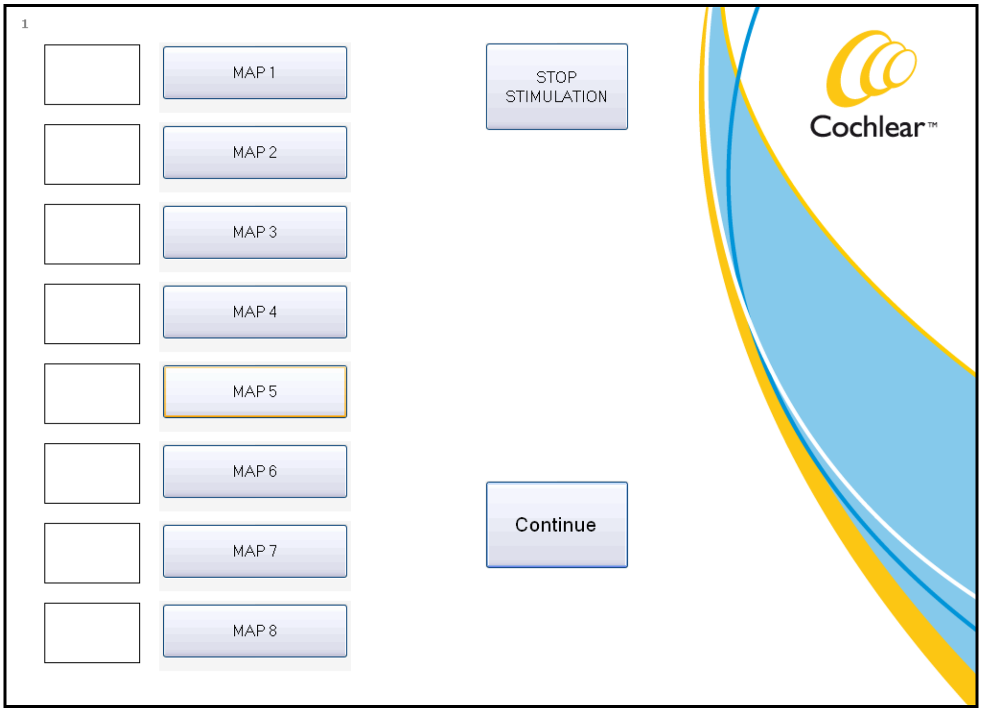

Figure 11: Initial 8 MAPs generated by the GA

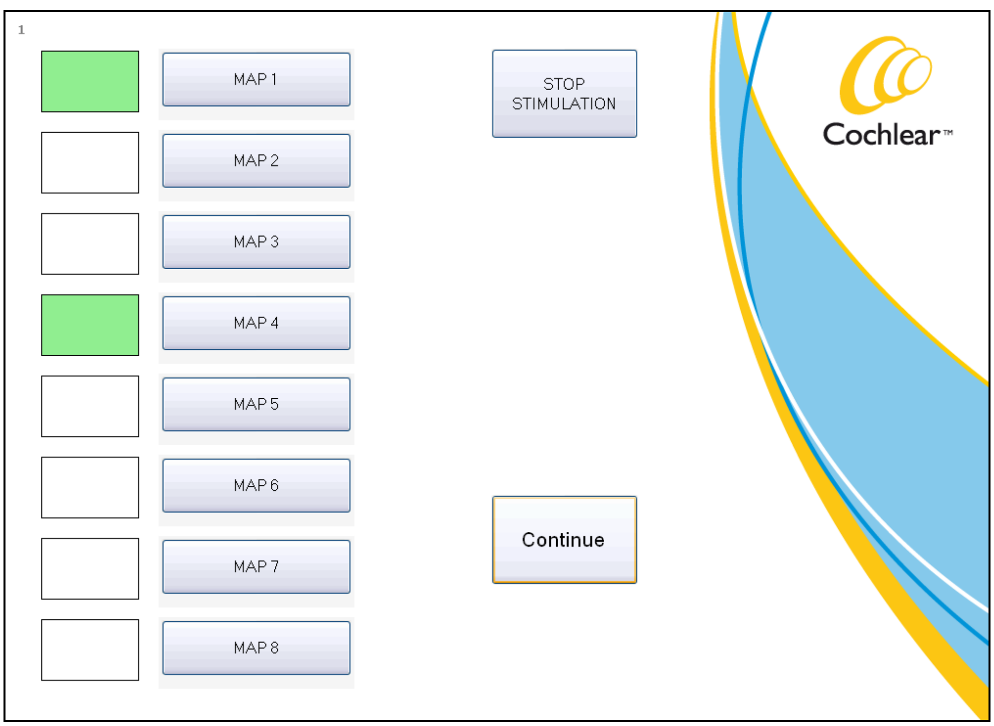

Figure 12: Initial set of MAPs with two selected as good by the listener

The selected MAPs are then randomly paired up by the algorithm. For each pair the parameters are recombined to create the next generation of MAPs, see Figure 13, with subsequent generations diverging from their predecessors via two principles (recombination). The first principle, crossover, is where the two MAPs are separated at a random site, and the parameters beyond this separation point are swapped, see Figure 14. The second principle, mutation, introduces a random change to the MAP parameters that was not initially part of the solution. The mutation principle is important as it introduces a parameter variation that may not have been present in preceding MAPs (e.g. if all selected MAPs had a stimulation rate of 500 or 1200 Hz, then mutation may introduce a stimulation rate of 900 Hz) (see Figure 15).

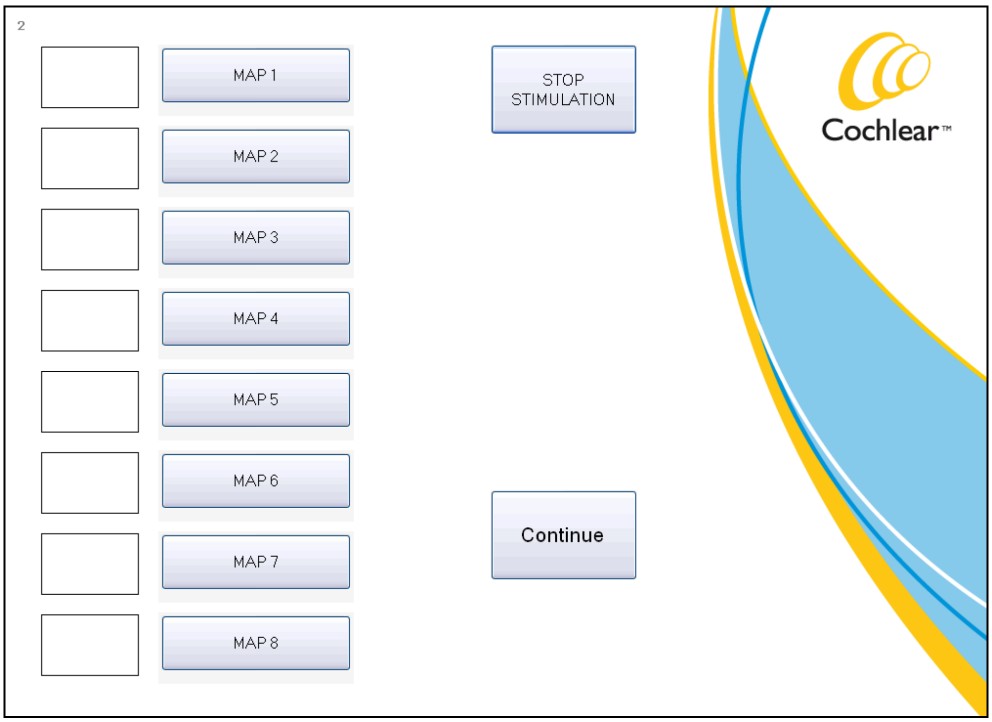

Figure 13: Next set of MAP options generated based on the 2 options previously selected

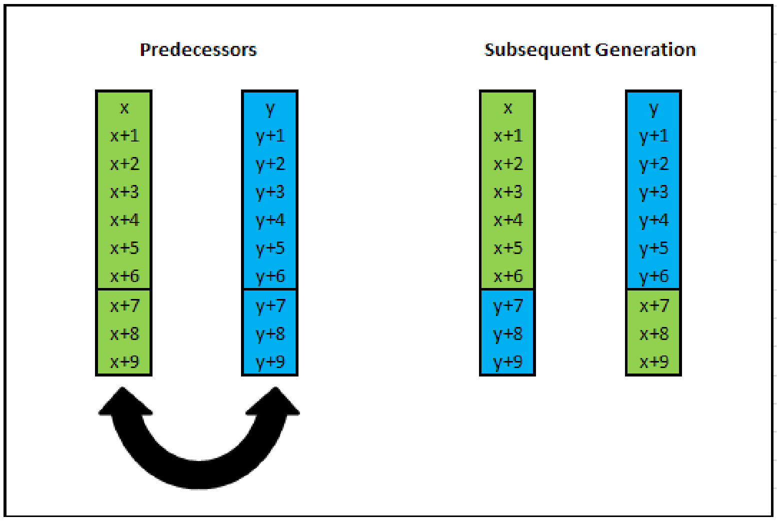

Figure 14: The crossover principle (adapted from Jones, 2005)

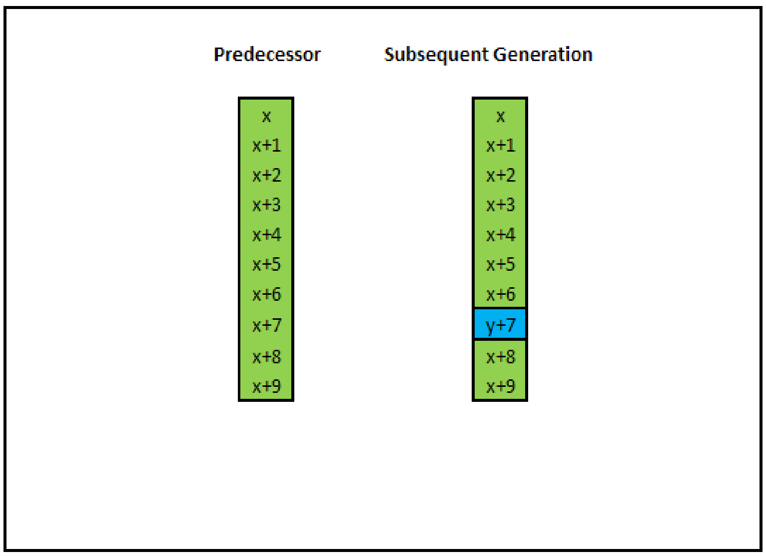

Figure 15: The mutation principle (adapted from Jones, 2005)

The evaluation, selection and recombination process is repeated, with CI users selecting MAPs that are progressively better for them for music listening, until the algorithm converges on the MAP it determines to be the best based on the choices made. In situations where users are inconsistent with their MAP selections, or where every/no MAP is selected for each generation, there is the potential for the process to continue for extended periods of time. If this were to happen then using the GA would become clinically impractical. For this reason, limits to the number of generations can be set and once this limit is reached, the algorithm will determine the most appropriate MAP given the data obtained.

The GA approach has been shown to be successful in optimising MAPs for speech perception. Wakefield et al. (2005) had five Esprit3G users select a MAP for speech perception using the GA approach. Participants listened to samples of speech and were asked to select those MAPs which gave the "most understandable, or clearest" speech signal from the GA-generated MAPs. Wakefield et al. (2005) found that, on average, the final MAP was selected within twenty generations. The results also showed that, when tested on speech perception tests with no additional time provided for participants to get used to the strategy, they performed almost identically with their new GA MAP to their original MAP generated by traditional methods. Similar outcomes have been obtained in other studies (e.g. Başkent et al., 2007) and when using a GA to optimise HA fittings (Durant et al., 2004).

Given the success of using a GA to create a MAP for speech perception, it is plausible that a GA may prove successful in creating a MAP for other listening situations (e.g. music listening). Given the constraints associated with traditional MAPping sessions (i.e. the thousands of MAP combinations that can arise from varying the different stimulation rates, maxima, Q-values etc), a GA approach allows CI users to efficiently search a larger parameter space than is possible during a traditional session. Further, this process allows the individual recipient autonomy to select the MAP suited to their preferred music stimuli.

1-6. Statement of the Problem

Traditionally, CIs have been successful in improving speech perception in quiet for a significantly hearing impaired individual, but provide limited benefit with more complex stimuli such as music. The success of a CI for music listening can be judged on how well listeners perceive elements of music (pitch, melody, timbre, rhythm) as well as by how much a listener appreciates music. Currently, the perception and appreciation of music is significantly lower for CI users than their NH peers. This is significant as music enjoyment has been shown to be a contributor to QoL in implantees, and an improvement in a CI user's music enjoyment relates to an improvement in QoL. Both the enjoyment and perception of music can be affected by the MAP programmed into a speech processor.

Setting the parameters for a MAP can prove challenging due to the large number of parameter combinations and interaction between parameters when making adjustments. In addition, MAPs are traditionally set for speech stimuli and not music stimuli. As mentioned, research has shown that a GA can be used to obtain a useful MAP for speech perception in quiet. In view of the previously mentioned issues related to creating a MAP for music, and the generally low music appreciation levels of many adult recipients, this study proposes to assess the usefulness of a GA to generate a MAP for music listening in CI recipients.

CI users created a custom MAP using a GA. To evaluate the GA MAP, participants were assessed on a series of music tests involving the perception of pitch, timbre and melody with their GA MAP and their original MAP. Participants also compared their GA and original MAP for enjoyment of music in everyday life. Additionally, feedback was sought from participants regarding the GA programming software to assess its suitability for use in a clinical setting.

The following four research questions were proposed:

1. How would a GA-generated MAP compare to a traditionally obtained MAP for timbre recognition?
2. How would a GA-generated MAP compare to a traditionally obtained MAP for melody perception?
3. How would a GA-generated MAP compare to a traditionally obtained MAP for pitch discrimination?
4. How would a GA-generated MAP compare to a traditionally obtained MAP for subjective ratings of music enjoyment?

2. METHOD

Ethical approval for this study was obtained from the Upper South Health and Disability Ethics Committee and from The University of Canterbury Human Research Ethics Committee.

2-1. PARTICIPANTS

Participants were recruited from the SCIP-A via an information sheet and consent form that was mailed out via a representative from SCIP-A. To be eligible to take part, participants were required to: (a) be at least 18 years of age; (b) have at least six months experience with a Nucleus Freedom CI; (c) have a stable MAP; (d) have full electrode insertion; (e) be post-lingually deaf; (f) have a good working knowledge of English; and (g) have no major cognitive or physical impairments that would affect their ability to undertake required tasks.

Seven adult CI users (2 female, 5 male) consented to take part in the study. The participants ranged in age from 20 to 79 years (mean: 45 years). Their average experience with a CI was 32 months (range: 12-73 months). All participants used the ACE strategy. Further details about the participants are presented in Table 1.

Subject (Sex)	Age (Years)	Duration of Profound Hearing Loss (Years)	CI Ear	CI Use (Months)	Speech Perception HINT (%)	Stimulation Rate (Hz)	Maxima	Music Experience Score[1]	Music Listening Score (pre-deafness)[2]	Music Listening Score (post-deafness)[2]
1 (M)	25	22	R	19	100	900	8	0	2	3
2 (M)	60	5	R	21	96	900	8	2	4	0
3 (F)	32	10	R	73	98	900	8	2	3	2
4 (M)	57	5	R	34	100	900	8	1	4	2
5 (F)	20	14	R	23	100	250	8	1	0	1
6 (M)	79	50	R	12	98	900	8	3	4	4
7 (M)	42	4	L	39	100	1200	12	3	4	1

Table 1: Summary of participant factors

[1] The Music Experience Score was calculated based on the length of total experience the individual had with music lessons (both theory and practical). This was assessed in the Music Training and Background Questionnaire. A score of '0' meant no formal training; '1' meant less than 3 years of formal training; '2' meant 3-5 years of formal training; and a score of '3' meant more than 5 years of formal training.

[2] The Music Listening Score was calculated based on how often the individual reported that they chose to listen to music pre- and post-implant. This was assessed in the Music Training and Background Questionnaire. A score of '0' meant never; '1' meant occasionally; '2' meant sometimes; '3' meant often; and a score of '4' meant very often.

2-2. MATERIALS

2-2-1. QUESTIONNAIRES

A Music Training and Background Questionnaire was developed and subsequently used to ascertain the participants' listening experience, frequency of music listening, and enjoyment scores pre-deafness and post-implantation (Appendix A). This questionnaire was similar to the one used by Looi et al. (2008). A questionnaire on the participants' experience using the Genetic Algorithm was also administered in session 2 (Appendix B); this questionnaire was developed by Cochlear Ltd. Americas.

2-2-2. LISTENING DIARY

A listening diary was created for the purpose of this study (Appendix C). The diary pages contained a space for participants to describe the different listening situations they found themselves in, and to comment on their experience in that situation. For each situation participants were asked to make comparisons in terms of which MAP was more pleasant, more natural, and better using a visual analogue scale. An example of the scale is shown in Figure 16. The midpoint of the scale is considered neutral and participants were required to make one mark along the scale, depending on the extent to which they preferred one MAP over the other. A mark to the left side of the mid-point meant that the original MAP was preferred and a mark to the right side meant that the GA MAP was preferred. The difference between the neutral mid-point and the mark is indicative of the extent, or magnitude, of preference.

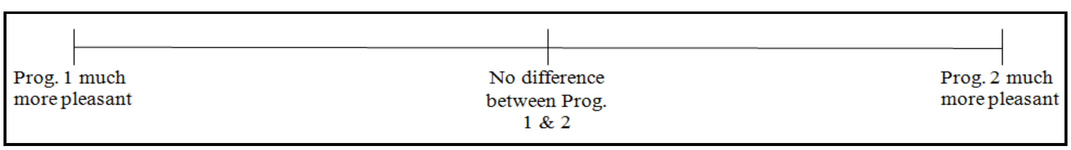

Figure 16: Visual analog scale for the listening diary

2-2-3. SPEECH PERCEPTION TEST

The Hearing-In-Noise Test (HINT) (Nilsson et al., 1994) was used to assess speech perception. The HINT consists of 25 phonemically balanced lists of 10 sentences each. The recording used was of a New Zealand female speaker and is the same one that is currently used by SCIP-A. The level of presentation was set so that the calibration tone was at 55 dB-A at the participant's ear, consistent with the procedures used at SCIP-A.

2-2-4. Modified Music Test Battery

The Music Test Battery (MTB) was designed by Looi et al. (2008) for their study. For this particular study, the MTB was modified for New Zealand participants and shortened to test for three components of music: pitch, melody and timbre. Tests were presented in a randomised order, and the stimuli within each test were also randomised. The level of presentation was set so that the calibration tone was at 65 dB-A at the participant's ear. The tests are described below; the reader is referred to Looi et al. (2008) for specific details regarding the recording of the actual stimuli.

Timbre Test

The timbre test comprised of two subtests. The first involved identifying 12 single instruments, and the second involved identifying 12 music ensembles. The single instruments were the bass drum, cello, clarinet, drum kit, female singer, flute, guitar, male singer, piano, trumpet, violin and xylophone. The music ensembles were a cello with piano, choir, country and western band, female singer with piano, jazz band, male and female singer with piano accompaniment, male singer with piano, orchestra, percussion, rock band, string quartet, and violin with piano. For each subtest, a 5 second excerpt of each stimulus was presented in a randomised manner. Participants were required to identify which instrument/ensemble was presented from a closed-set list of the 12 instruments or ensembles. Each 5-second excerpt was presented four times throughout the test, for a total of 48 presentations for each subtest. Again, a percentage-correct score was subsequently calculated.

Melody Test

The stimuli for this test were eight familiar melodies played once by the preset clarinet and once with the preset oboe sounds on a *Yamaha PSR-276* portable keyboard. The original study by Looi et al. (2008) used ten melodies; however Advance Australia Fair and Waltzing Matilda were removed as they were less likely to be familiar to New Zealand listeners. The melodies used were Baa Baa Black Sheep, For He's a Jolly Good Fellow, Happy Birthday, Jingle Bells, O Come O Ye Faithful, Old McDonald, Silent Night, and Twinkle Twinkle Little Star. During testing, participants were presented with the first 15 seconds of each melody, presented in random order. Participants are then required to choose from a list of the eight melodies which they thought they had heard. Each melody was presented twice for a total of 16 presentations, and a percentage-correct score was subsequently calculated.

Pitch Test

The pitch test involved six subtests. The stimuli were pairs of the vowel /a/ either sung by a male or female. The six subtests are presented in Table 2. During the test, participants are presented with the two sung vowels and asked whether the first or second was higher in pitch. For half of the presentations the first /a/ was higher, and for the other half the second /a/ was higher in pitch.

Subtest	Stimulus	Interval
1	Male sung /a/	Full Octave
2		Half Octave
3		Quarter Octave
4	Female sung /a/	Full Octave
5		Half Octave
6		Quarter Octave

Table 2: Summary of the pitch perception subtests

2-3. EQUIPMENT

An IBM ThinkPad with the following Cochlear Ltd. programs was used to generate the GA MAP and program the participant's speech processor: Cochlear Self Directed Fitting, Custom Sound™ 2.0 and Custom Sound™ 3.0. The standard Cochlear programming pod and cables were also used. The modified MTB was presented through the MACarena computer program (Lai & Dillier, 2002) run on the IBM ThinkPad, which was connected to a Crown D-75 amplifier and JBL Ti 100 loudspeaker. A Sony Mini System MHC GT-22 was used to present music to the participants when generating their GA MAP.

2-4. PROCEDURE

Participants took part in three sessions over a period of approximately six weeks, and completed the Music Training and Background Questionnaire, as well as the Listening Diary at home.

2-4-1. *Session One – Defining the GA parameter space*

The first session took place in a sound treated room at the University of Canterbury's Speech and Hearing Clinic, Bay Audiology in Cromwell and, in cases where participants were unable to make it to these clinics, in an enclosed room with a background noise level of less than 40 dB (A). Participants were firstly assessed on the modified MTB using their everyday MAP. The three tests, and subtests, were presented in a random order for each participant.

After this, the parameter space for the GA software was defined. In order to do this, new MAPs were created for 3 different stimulation rates and 3 different maxima (i.e. 900 Hz, 12 maxima; 900 Hz, 10 maxima; 900 Hz, 8 maxima; 1200 Hz, 12 maxima; 1200 Hz, 10 maxima; 1200 Hz, 8 maxima; 500 Hz, 12 maxima; 500 Hz, 10 maxima; 500 Hz, 8 maxima). Each MAP used an ACE strategy with a pulse width of 25, and the stimulation mode of the participant's everyday MAP.

Firstly, T and C levels for electrodes 22, 16, 11, 6 and 1 were measured for each of these nine MAP parameters. The method of doing this was the same for each of the nine MAPs. Firstly, T-levels were measured using an ascending-descending approach. Participants were required to report the number of tones they heard, with the criteria for threshold being an accurate count of the beeps for at least two out of three ascending trials.

Then the C-levels were obtained for the same electrodes. The current level was increased from threshold and participants were asked to rate the perceived loudness of a tone on a five-point scale ranging from soft to comfortably loud. C-levels were set at the highest level where the tone was judged to be comfortably loud by the participant. Once all of the C-levels were set, they were globally decreased by 25% of the dynamic range to avoid overstimulation.

Finally, participants listened through the MAP and were asked to report on the loudness and sound quality of the MAP. Based on their feedback, adjustments were made to the MAP until the participant was satisfied with how the MAP sounded. The MAP was then saved and the process repeated for the nine sets of MAP parameters. Participants were then given the Music Training and Background Questionnaire to complete at home.

2-4-2. *Session Two – Programming the GA MAP*

In order to reflect a real-world listening environment, session two was conducted in a non-sound-treated room. For two participants this session occurred one week after their initial session, and for the remaining five this session took place later on the same day. For five participants this was an office at the University of Canterbury, and for the remaining two this session took place in a room at their house.

For this session, participants were asked to bring along three compact discs (CDs) of their favourite music, or music that they would like to customise their MAP for. The CDs were then played through the stereo and participants were asked to adjust the volume to a comfortable listening level for them.

Participants were then connected to the computer via the programming pod and the initial set of eight MAPs was generated as per the description in the Introduction, and displayed on the screen (see Figure 10 in the Introduction). Participants then listened to the music through each created MAP by clicking on the tab that had the MAP's name (i.e. MAP 1...MAP 8). If the participant liked the sound of a MAP, they selected it by clicking the white box to the left of the tab. Participants were instructed to select as many, or as few, MAPs as they wanted.

Once they were happy with their selections, participants clicked on the 'continue' tab and the parameters of the selected MAPs were recombined to create eight new MAPs, as per the description in the Introduction. This process was repeated until the software statistically determined the optimal MAP for the participant based on their selections. Throughout this process participants were able to change between music tracks and/or adjust the volume settings as they would do at home.

Once the GA software had derived the optimal MAP, the participant was asked if they could identify which of two MAPs (the new GA MAP and their original MAP) was which. All participants could recognise their original MAP as different from their GA MAP. The GA MAP was then written to a program slot in the participant's processor that was not currently used by the participant.

At the end of this session, participants completed the GA Fitting Questionnaire and were instructed on how to fill out the listening diary. Participants were given the opportunity to ask any questions regarding the study. Once participants felt comfortable with what was required of them, they were encouraged to compare their GA MAP with their everyday MAP in a variety of different listening situations over the next four weeks, recording their notes in their Listening Diary.

2-4-3. Session Three – Assessment of the GA MAP

Session three took place in the same location as the first session for all but one participant (P3), for whom the session took place in a similar sound-treated room. During this session, participants were re-assessed on the modified MTB, followed by the HINT sentence test, using their GA MAP. Again the tests were presented via a free-field speaker. For the HINT sentence test, participants were assessed using one list presented in quiet in order to assess whether there were any changes to their speech perception ability with the GA MAP.

Participants were then debriefed, and asked to provide their general opinion on the GA MAP. Finally, they were asked if they would like to keep their new GA MAP alongside their original MAP. If they did not wish to keep their GA MAP, their processor was reset to its pre-study condition. A copy of the participants' GA MAP was sent to SCIP-A for their records.

2-5. Data Analysis

Statistical analyses were performed using the software SPSS 17.0. All analyses used 2-tailed statistical tests with a significant p-value of $p \leq 0.05$. Unless otherwise stated, due to the small number of participants non-parametric Wilcoxon Signed Ranks Tests were used to compare the results obtained with the GA MAP to those obtained with the original MAP. All correlations were done using Pearson's R.

Participant factors used for correlational analyses were obtained from the Music Training and Background Questionnaire (Appendix A). These factors were the age of the participant, time with CI (months), duration of profound hearing loss prior to implantation (years), prior music training experience, frequency of music listening pre-hearing, and frequency of music listening post-hearing loss. The prior music training experience score was calculated from the number of years that the participant had spent studying music (both theory and practical at school and/or privately). A score of '0' meant the participant had no formal training; '1' meant less than 3 years formal training'; '2' meant 3-5 years of formal training; and a score of '3' meant more than 5 years of formal training. The music listening frequency scores were calculated from questions 1 and 2 of the MTBQ, with responses made on a 4-point scale where '0' corresponded to never; '1' to occasionally; '2' to sometimes; '3' to often; and '4' to very often.

3. RESULTS

This section compares the GA MAPs with the original MAPs. It begins with a report of the MAP characteristics. This is followed by a comparison of participant performance on the speech perception task and the MTB. Following this is a report of the listening diary ratings for the different listening situations, and finally the participants' response to the GA Fitting Questionnaire is detailed.

3-1. TIME TAKEN TO GENERATE GA MAP

Table 3 shows the length of time and number of generations for each participant to generate their GA MAP using the GA software. The results show that the average time required for the software to converge on a GA MAP was 35 minutes (range: 13-72 minutes), and that the average number of generations required to converge on a GA MAP was 16.6 (range: 10-31). P4 was the only participant whose GA MAP was the result of a forced convergence.

Participant	Time (Minutes)	Number of Generations
1	40	10
2	17	16
3	22	14
4	72	31 (forced convergence)
5	13	11
6	46	19
7	35	15
Mean	35	16.6

Table 3: Number of generations and time taken for participants to generate a MAP using the GA software

3-2. MAP CHARACTERISTICS

A summary of the maxima, stimulation rate per channel, total stimulation rate, frequency allocation table, and SmartSound features for each participant's original and GA MAPs can be seen in Table 4. It can be seen that all participants created a GA MAP with 12 maxima. Furthermore, while five participants' original MAP had a stimulation rate of 900Hz (P5 had a stimulation rate of 250 Hz, and P7 had a stimulation rate of 1200 Hz), all but one participant created a GA MAP with a stimulation rate of 900 Hz (P1 created a MAP with a stimulation rate of 500 Hz). It can also be seen that four participants (P1, P5, P6 and P7) created a GA MAP with the same frequency allocation table as their original MAP, while three (P2, P3 and P4) created a MAP that reduced the frequency range mapped onto their electrodes. Finally, the table shows that all participants created a GA MAP with ADRO, that four participants (P1, P2, P5 and P7) created a MAP with Whisper, and one (P6) with Automatic Sensitivity Control (ASC).

Participant	Maxima		Stimulation Rate (Hz)		Total Stimulation (Hz)		Frequency Table		Smartsound Features	
	Original	GA	Original	GA	Original	GA	Original	GA	Original	GA
1	8	12	900	500	7200	6000	22	22	E (A)	E (A+W)
2	8	12	900	900	7200	10800	22	22-B	E (A)	E (A+W)
3	8	12	900	900	7200	10800	20	22-A	E (A+AS)	E (A)
4	8	12	900	900	7200	10800	22	22-A	E (A)	E (A)
5	8	12	250	900	2000	10800	20	20	E (A)	E (A+W)
6	8	12	900	900	7200	10800	21	21	E (A)	E (A+ AS
7	12	12	1200	900	14400	10800	22	22	E (A)	E (A+W)

Table 4: Comparison of MAP characteristics for each participant's original and GA MAP

Legend

Frequency Table			*Smartsound Features*
20:	188 – 6938 Hz	E:	Everyday
21:	188 – 6063 Hz	A:	ADRO
22:	188 – 5313 Hz	AS:	Automatic sensitivity control
22-A:	188 – 5063 Hz	W:	Whisper
22-B:	188 – 4563 Hz		

3-3. Speech Test Results

Figure 17 shows the percent of HINT sentences correctly identified by participants when using their original and GA MAPs. As a group, participants scored higher with their original MAP (99.0%) than with their GA MAP (89.0%), however statistical testing revealed that this difference was not significant (p=0.102). It can be seen that two participants (P1 and P7) scored 100% when using both their GA and original MAP, one participant (P3) was more accurate with their GA MAP, and four participants (P2, P4, P5 and P6) scored higher with their original MAP.

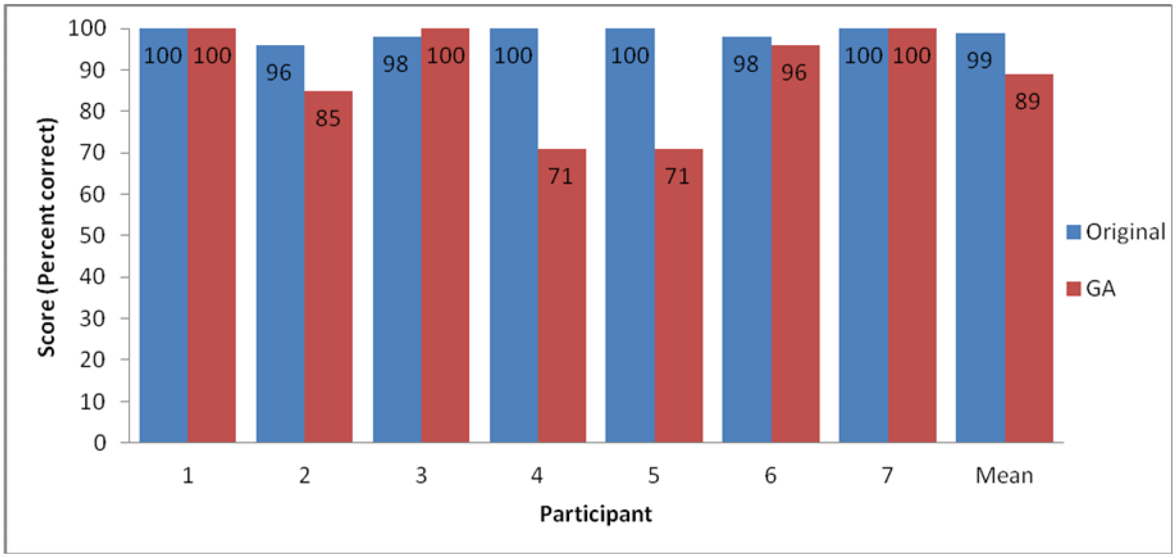

Figure 17: Comparison of original and GA MAP scores for speech perception using HINT sentences in quiet

3-4. Music Test Battery

A summary of the group's performance, expressed as a percent correct score, using the original and GA MAPs is reported in Table 5. Table 5Error! Reference source not found. also reports the mean performance (i.e. average of the original and GA MAP scores) for all participants.

Task	Original MAP	GA MAP	Averaged Score (GA + Original)
Single Instrument Identification	73.5 (R: 66.7-97.9)	69.6 (R: 43.8-97.9)	71.6 (SD: 14.0)
Ensemble Identification	49.7 (R: 33.3-79.2)	40.2 (R: 14.6-91.7)	45.0 (SD: 21.3)
Melody Identification	78.6 (R: 50.0-100)	87.5 (R: 43.8-100)	83.1 (SD: 20.0)
Pitch Ranking One-Octave Interval	96.7 (R: 89.6-100)	86.0 (R: 45.8-100)	91.4 (SD: 18.7)
Pitch Ranking Half-Octave Interval	88.4 (R: 75.0-100)	79.5 (R: 50.0-100)	83.9 (SD: 16.0)
Pitch Ranking Quarter-Octave Interval	69.0 (R: 53.1-100)	70.5 (R: 46.9-98.4)	69.8 (SD: 18.2)

Table 5: Mean Music Test Battery scores with original, GA, and averaged (GA and original) MAPs (% correct scores)

R= range; SD=Standard Deviation

In this MTB section, combined participant responses for some tasks are presented in a confusion matrix. The horizontal axis of the matrix represents the stimuli presented, and the vertical axis represents the participant responses. The highlighted cells indicate the percent of time that a stimulus was correctly identified while the white cells show the percent of time that a stimulus was incorrectly identified as another. For example, in Table 6 on the next page, when using their original MAP for the single instrument identification task, the drum kit was correctly identified 85.7% of the time but was identified as the timpani 14.3% of the time.

3-4-1. TIMBRE

Single Instrument Identification Task

For this task, participants were required to identify which instrument had played a 5-second musical excerpt. There were 12 instruments and each excerpt was presented four times, for a total of 48 presentations. On average, participants correctly identified more instruments with their original MAP (73.5%, SD=11.4) than with their GA MAP (69.6%, SD=16.8), however this difference was not statistically significant (p=0.528). Figure 18 shows the percent of instruments correctly identified by participants when using their original and GA MAPs. Four participants (P1, P2, P3 and P5) scored higher with their original MAP, two (P4 and P6) scored higher with their GA MAP, and one (P7) performed equally with both MAPs.

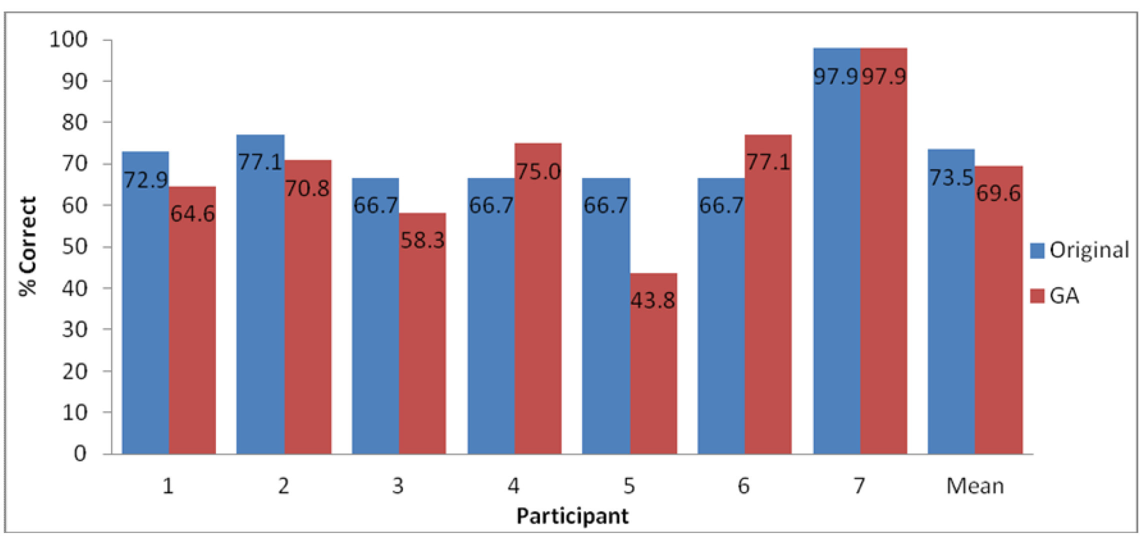

Figure 18: Comparison of original and GA MAP scores for single instrument identification task

Table 6 is a confusion matrix that shows the combined participant responses for the single instrument identification task using their original MAP. It shows that the most accurately recognised instrument was the male singer (100%) and that the least accurately recognised instrument was the clarinet (42.9%). Furthermore, the most common confusion made by participants was identifying the timpani as the drum kit (28.6%). Table 7 is a confusion matrix that details the combined participants' responses for the same task using their GA MAP. It shows that the most recognised instruments were the male and female singers (96.4%) and the least recognised instrument was the cello (35.7%). The most common confusion made by participants was identifying the clarinet as the flute (32.1%).

Response \ Stimuli	Cello	Clarinet	Drum Kit	Flute	Guitar	Piano	Timpani	Trumpet	Violin	Xylophone	Fem Singer	Male Singer
Cello	67.9	0	0	0	3.6	3.6	0	0	10.7	0	0	0
Clarinet	7.1	42.9	0	21.4	3.6	0	0	14.3	25.0	0	3.6	0
Drum Kit	3.6	0	85.7	3.6	0	0	28.6	0	0	3.6	0	0
Flute	3.6	21.4	0	53.6	0	0	0	0	7.1	0	0	0
Guitar	3.6	0	0	0	67.9	3.6	0	0	0	0	0	0
Piano	7.1	0	0	0	10.7	75.0	3.6	0	7.1	0	0	0
Timpani	0	0	14.3	0	0	0	67.9	0	0	0	0	0
Trumpet	0	7.1	0	3.6	0	0	0	82.1	0	0	0	0
Violin	7.1	21.4	0	17.9	0	7.1	0	3.6	50.0	0	3.6	0
Xylophone	0	7.1	0	0	14.3	10.7	0	0	0	96.4	0	0
Fem Singer	0	0	0	0	0	0	0	0	0	0	92.9	0
Male Singer	0	0	0	0	0	0	0	0	0	0	0	100

Table 6: Confusion matrix for average participants' responses for the single instrument identification task when using their original MAP (percent correct scores)

Response \ Stimuli	Cello	Clarinet	Drum Kit	Flute	Guitar	Piano	Timpani	Trumpet	Violin	Xylophone	Fem Singer	Male Singer
Cello	35.7	10.7	0	7.1	0	0	0	0	14.3	0	0	0
Clarinet	3.6	39.3	0	25.0	0	0	0	14.3	17.9	0	0	0
Drum Kit	0	0	92.9	0	0	7.1	17.9	0	3.6	3.6	0	0
Flute	0	32.1	0	46.4	7.1	0	0	3.6	3.6	0	0	0
Guitar	10.7	0	0	0	67.9	7.1	0	0	3.6	0	0	0
Piano	3.6	3.6	0	3.6	17.9	67.9	0	0	7.1	3.6	0	0
Timpani	0	0	3.6	0	0	0	82.1	0	0	0	0	0
Trumpet	28.6	0	0	0	3.6	3.6	0	71.4	0	0	0	0
Violin	10.7	10.7	0	14.3	0	0	0	7.1	46.4	0	3.6	0
Xylophone	0	3.6	3.6	3.6	3.6	14.3	0	3.6	3.6	92.9	0	0
Fem Singer	0	0	0	0	0	0	0	0	0	0	96.4	3.6
Male Singer	7.1	0	0	0	0	0	0	0	0	0	0	96.4

Table 7: Confusion matrix for average participants' responses for the single instrument identification task when using their GA MAP (percent correct scores)

Ensemble Identification Task

For this task, participants were required to identify which ensemble had played a 5-second musical excerpt. There were 12 different ensembles and each was presented four times, for a total of 48 presentations. On average, participants correctly identified more ensembles when using their original MAP (49.7%, SD=17.7) than with their GA MAP (40.2%, SD=24.7), however statistical testing did not show this difference to be significant (p=0.108). The percent of ensembles correctly identified by participants when using their original and GA MAPs is shown in Figure 19. Six participants correctly identified more ensembles when using their original MAP, while one participant (P7) performed better with their GA MAP.

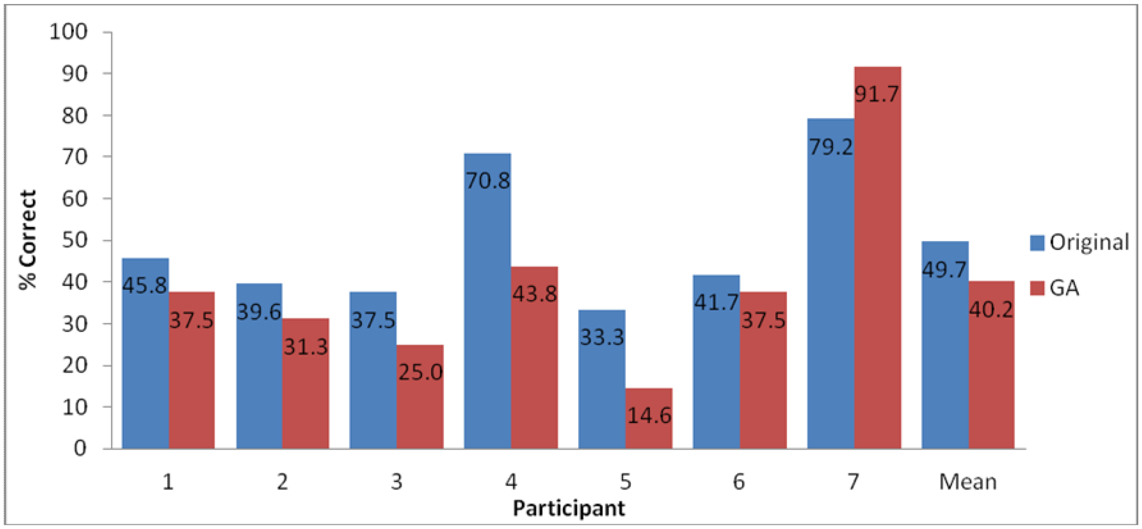

Figure 19: Comparison of original and GA MAP scores for ensemble identification task

Table 8 is a confusion matrix that shows the combined group's participant responses for the ensemble identification task using their original MAP. It shows that the most recognised instrument was the female with piano (67.9%) and that the least recognised ensemble was the string quartet (28.6%). The most common confusion made by participants was identifying the string quartet as an orchestra (32.1%). Table 9 is a confusion matrix for the combined participant responses for the same test using a GA MAP. It shows that the most recognised ensembles were the choir and female with piano (60.7%), and that the least identified ensemble was the male with female and piano (17.9%). The most common confusion made was identifying the cello with piano as the violin with piano (32.1%).

Response \ Stimuli	Country Western	Choir	Jazz Band	Orchestra	Percussion	Rock Band	String Quartet	Violin + Piano	Cello + Piano	Male Singer + Piano	Fem Singer + Piano	M + F Singer + Piano
Country Western	**35.7**	7.1	3.6	0	7.1	10.7	3.6	0	0	14.3	7.1	7.1
Choir	0	**64.3**	0	3.6	0	3.6	0	0	0	0	0	10.7
Jazz Band	10.7	0	**35.7**	7.1	10.7	17.9	7.1	7.1	3.6	0	3.6	0
Orchestra	7.1	10.7	14.3	**50.0**	0	3.6	32.1	7.1	21.4	0	0	3.6
Percussion	3.6	0	0	14.3	**60.7**	0	3.6	3.6	10.7	0	0	0
Rock Band	7.1	3.6	7.1	0	7.1	**64.3**	7.1	0	0	3.6	7.1	0
String Quartet	10.7	3.6	21.4	7.1	10.7	0	**28.6**	21.4	7.1	0	3.6	0
Violin + Piano	21.4	0	14.3	10.7	3.6	0	3.6	**46.4**	7.1	0	0	0
Cello + Piano	3.6	0	3.6	0	0	0	10.7	14.3	**46.4**	0	0	0
M Singer + Piano	0	7.1	0	0	0	0	3.6	0	0	**64.3**	3.6	14.3
F Singer + Piano	0	3.6	0	3.6	0	0	0	0	0	0	**67.9**	32.1
M + F Singer + Piano	0	0	0	3.6	0	0	0	0	3.6	17.9	7.1	**32.1**

Table 8: Confusion matrix for average participants' responses for the ensemble identification task when using their original MAP (percent correct scores)

Response \ Stimuli	Country Western	Choir	Jazz Band	Orchestra	Percussion	Rock Band	String Quartet	Violin + Piano	Cello + Piano	Male Singer + Piano	Fem Singer + Piano	M + F Singer + Piano
Country Western	**25.0**	7.1	14.3	0	0	14.3	3.6	0	3.6	7.1	14.3	14.3
Choir	0	**60.7**	0	3.6	0	0	14.3	0	0	3.6	0	10.7
Jazz Band	0	0	**25.0**	7.1	7.1	7.1	10.7	10.7	0	3.6	7.1	3.6
Orchestra	7.1	3.6	10.7	**42.9**	7.1	10.7	25.0	3.6	14.3	7.1	0	0
Percussion	14.3	10.7	0	14.3	**50.0**	14.3	0	7.1	0	0	0	7.1
Rock Band	25.0	0	14.3	3.6	21.4	**42.9**	3.6	0	0	7.1	0	3.6
String Quartet	3.6	0	7.1	10.7	7.1	3.6	**28.6**	17.9	10.7	3.6	0	3.6
Violin + Piano	14.3	3.6	10.7	3.6	0	3.6	10.7	**42.9**	32.1	0	0	0
Cello + Piano	10.7	0	10.7	3.6	7.1	0	3.6	14.3	**35.7**	3.6	0	3.6
M Singer + Piano	0	3.6	0	0	0	0	0	0	0	**50.0**	10.7	10.7
F Singer + Piano	25.0	7.1	14.3	0	0	14.3	3.6	0	3.6	7.1	**14.3**	14.3
M + F Singer + Piano	0	60.7	0	3.6	0	0	14.3	0	0	3.6	0	**10.7**

Table 9: Confusion matrix for average participants' responses for the ensemble identification task when using their GA MAP (percent correct scores)

Difference between single instrument and ensemble identification tasks

In view of existing research suggesting that implant recipients are better on tasks with simple stimuli, as opposed to more complex stimuli, a Wilcoxon signed-ranks test was calculated to see if there was any significant difference between performance on the single instrument and the ensemble identification tasks. The results showed that the scores on the single instrument identification task were significantly better than the ensemble identification task for the original MAP (p=0.028), GA MAP (p=0.018), and when the scores for both MAPs were combined (p=0.001).

Correlations between timbre task scores and subject variables

A Pearson's R correlation was calculated to determine if there were any correlations between individual participant factors and performance on the instrument identification tasks. There were no significant correlations found. A list of correlations can be seen in Table 10.

Participant Factor	Single Instrument Identification Task		Ensemble Identification Task	
Sex	-0.406	p=0.367	-0.547	p=0.204
Age	-0.042	p=0.929	0.170	p=0.716
Time with cochlear implant	0.031	p=0.947	0.100	p=0.832
Duration of profound hearing loss pre-implant	-0.387	p=0.392	-0.378	p=0.404
Music experience score	0.423	p=0.345	0.206	p=0.657
Pre-hearing loss listening score	0.336	p=0.461	0.523	p=0.229
Post-implant listening score	-0.420	p=0.348	-0.089	p=0.850

Table 10: Table of correlations between participant factors and performance on the timbre tasks

3-4-2. MELODY

For this task participants were required to identify excerpts of 8 familiar melodies played 2 times each for a total of 16 presentations. It can be observed that group performance on this task was better with the GA MAP (87.5%, SD=20.4) than with the original MAP (78.6%, SD=20.0). Statistical testing revealed that this result was statistically significant (p=0.045). The percent of melodies that participants correctly identified when using their original and GA MAP is shown in Figure 20. It shows that five participants correctly identified more melodies when using their GA MAP, while one (P5) performed poorer on this task when using their GA MAP and one participant (P2) scored 100% using both MAPs.

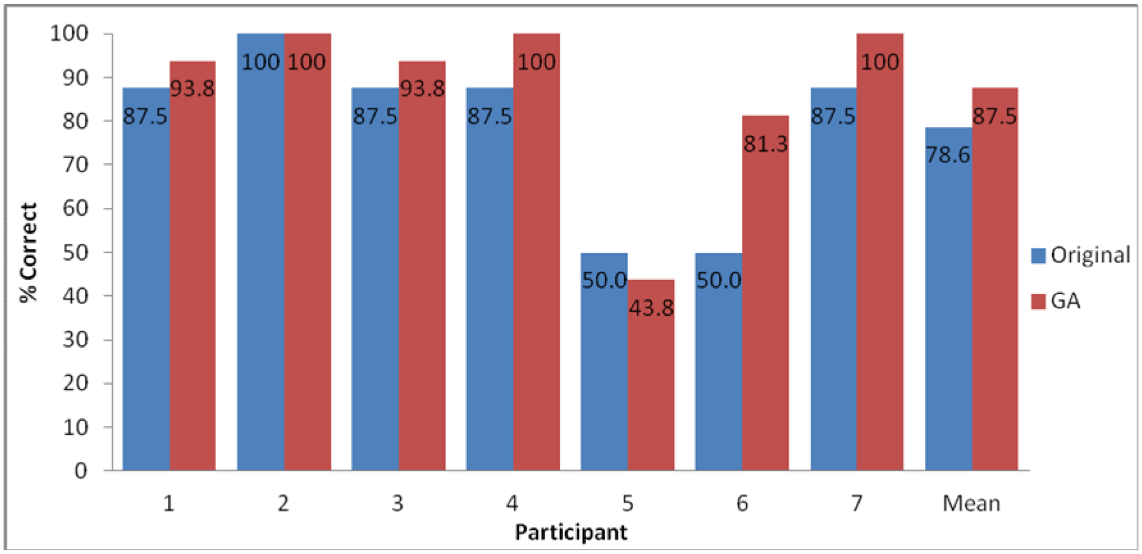

Figure 20: Comparison of original and GA MAP for melody identification task

Table 11 is a confusion matrix that shows the combined participant responses for the melody identification task using their original MAP. It shows that the most recognised melodies were *For He's a Jolly Good Fellow* and *Happy Birthday* (92.9%), and the least recognisable melody was *Baa Baa Black Sheep* (50.0%). It also shows that the most common confusion was identifying *Twinkle Twinkle* as *Baa Baa Black Sheep* (42.9%). Table 12 is a confusion matrix that shows the combined subjects' responses for the same test using their GA MAP. It can be seen that the most recognised melodies were *Happy Birthday* and *Silent Night* (100%), while the least recognised melody was *Twinkle Twinkle* (64.3%). Furthermore, it can be seen that again the most common confusions were participants identifying *Twinkle Twinkle* as *Baa Baa Black Sheep*, and *Baa Baa Black Sheep* as *Twinkle Twinkle* (14.3%).

Response \ Stimuli	Baa Baa Black Sheep	Jolly Good Fellow	Happy Birthday	Jingle Bells	Old McDonald	O Come O Ye Faithful	Silent Night	Twinkle Twinkle
Baa Baa Black Sheep	50.0	0	0	0	14.3	0	0	14.3
Jolly Good Fellow	0	92.9	0	7.1	7.1	0	7.1	0
Happy Birthday	0	0	92.9	0	0	7.1	0	7.1
Jingle Bells	7.1	0	0	85.7	0	0	0	0
Old McDonald	0	7.1	0	0	64.3	7.1	0	0
O Come O Ye Faithful	0	0	0	7.1	0	78.6	7.1	0
Silent Night	0	0	7.1	0	0	0	85.7	0
Twinkle Twinkle	42.9	0	0	0	14.3	7.1	0	78.6

Table 11: Confusion matrix for average participants' responses for the melody identification task when using their original MAP

	Stimuli: Baa Baa Black Sheep	Jolly Good Fellow	Happy Birthday	Jingle Bells	Old McDonald	O Come O Ye Faithful	Silent Night	Twinkle Twinkle
Response: Baa Baa Black Sheep	85.7	0	0	0	14.3	7.1	0	14.3
Jolly Good Fellow	0	92.9	0	0	7.1	0	0	7.1
Happy Birthday	0	0	100	0	0	0	0	0
Jingle Bells	0	0	0	85.7	0	0	0	7.1
Old McDonald	0	7.1	0	7.1	64.3	0	0	7.1
O Come O Ye Faithful	0	0	0	7.1	0	92.9	0	0
Silent Night	0	0	0	0	0	0	100	0
Twinkle Twinkle	14.3	0	0	0	14.3	0	0	64.3

Table 12: Confusion matrix for average participants' responses for the melody identification task when using their GA MAP

Correlations between melody task scores and subject variables

A Pearson's R correlation was calculated to determine if there were any correlations between individual participant factors and performance on the melody identification task. A list of correlations can be seen in Table 13. A significant strong positive correlation was found between the pre-hearing loss listening score and performance on the melody identification task with the GA MAP (p=0.019). There were no other significant correlations found.

Participant Factor	Original MAP		GA MAP	
Sex	-0.335	p=0.463	-0.627	p=0.132
Age	-0.058	p=0.901	0.373	p=0.410
Time with cochlear implant	0.376	p=0.406	0.268	p=0.562
Duration of profound hearing loss pre-implant	-0.686	p=0.089	-0.273	p=0.554
Music experience score	-0.133	p=0.775	0.183	p=0.694
Pre-hearing loss listening score	0.476	p=0.280	0.835*	p=0.019
Post-implant listening score	-0.442	p=0.321	0.001	p=0.999

Table 13: Table of correlations between participant factors and performance on the melody identification task

* = p <0.05

3-4-3. PITCH

For this task participants had to identify which of two sung vowels were higher in pitch. The notes were separated by either a full octave, half an octave, or a quarter octave. A paired t-test was used to assess whether there was a significant difference between the male and female stimuli used for the pitch ranking task. The results showed that there was no significant difference between the male and female sung vowels for the original MAP (p=0.239), however there was a significant difference between the male and female sung vowels for the GA MAP (p=0.012). Due to the significant difference between male and female sung vowels for the GA MAP, comparisons between the MAPs are made for male sung vowels, female sung vowels, and then combined (male and female) sung vowels.

Full Octave Interval

Table 14 provides the results for this subtest. For the male-sung vowel, the group score was higher with the original MAP (95.2%, SD=5.4) than with the GA MAP (92.3%, SD=17.0), however this difference was not significantly different (p=0.891). Three participants (P1, P2 and P7) performed better on this task with their GA MAP, while two (P3 and P5) performed better on the task with their original MAP, and two (P4 and P6) scored 100% with both MAPs. A similar pattern was found for the female-sung vowel. On average, participants scored higher with their original MAP (98.2%, SD=3.1) than with their GA MAP (79.8%, SD=31.8). Again this difference was not statistically significant (p=0.066). It can be seen that four participants (P1, P2, P4 and P5) performed better with their original MAP while three participants (P3, P6 and P7) scored 100% with both MAPs.

%-Correct	Male Sung Vowel		Female Sung Vowel		Combined (Male + Female)	
Participant	Original	GA	Original	GA	Original	GA
1	95.8	100	100	95.8	97.9	97.9
2	95.8	100	100	95.8	97.9	97.9
3	100	95.8	100	100	100	97.9
4	100	100	95.8	29.2	97.9	64.6
5	87.5	54.2	91.7	37.5	89.6	45.8
6	100	100	100	100	100	100
7	87.5	95.8	100	100	93.8	97.9
Mean	95.2	92.3	98.2	79.8	96.7	86.0

Table 14: Comparison of original and GA MAP scores for full-octave interval pitch ranking task (male and female sung vowels)

When combining the scores for the male and female conditions, the data shows that, on average, the participants were more accurate with their original MAP (96.7%, SD=4.5) than with their GA MAP (86.0%, SD=25.3) (Figure 21), but again this difference was not significantly different (p=0.205). Three participants (P3, P4 and P5) scored higher on this task when using their original MAP, while three participants (P1, P2 and P6) performed equally well with both MAPs, and one participant (P7) was able to correctly identify more presentations with their GA MAP.

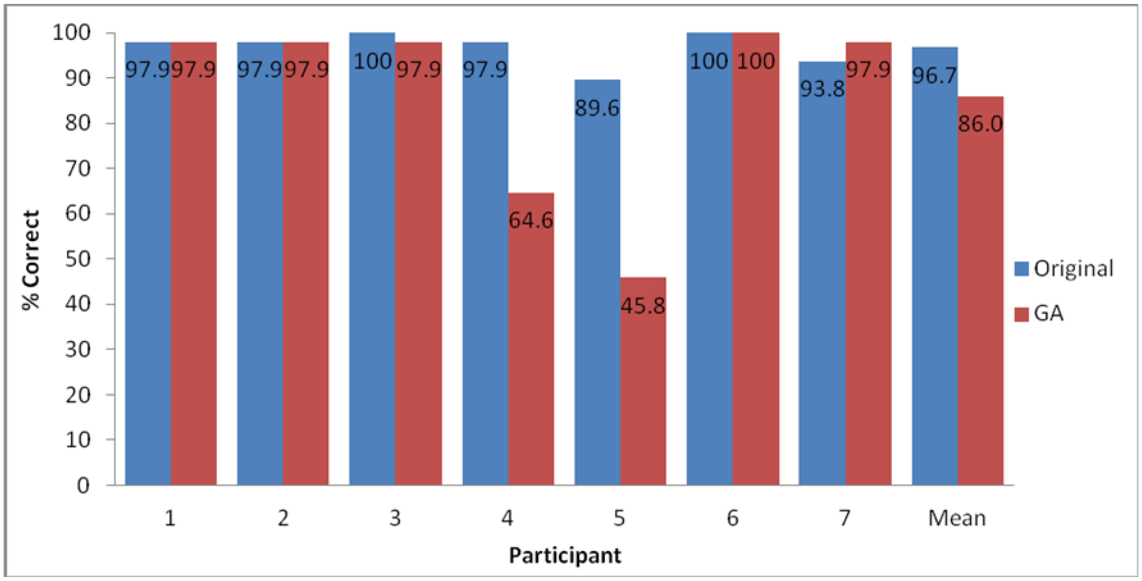

Figure 21: Comparison of combined (male and female) original and GA MAP scores for pitch ranking task (full octave interval)

Half-octave interval

Table 15 provides the individual participants' results for this subtest. As a group, participants scored higher with their original MAP (87.5%, SD=11.9) than with their GA MAP (83.3%, SD=12.7) for the male-sung vowel, however this difference was not statistically significant (p=0.197). It can be seen that three participants (P1, P4 and P6) scored higher with their original MAP while three (P2, P5 and P7) performed the same and one (P3) performed better with the GA MAP. For the female-sung vowel, participants, as a group, performed better with their original MAP (89.3%, SD=11.1) than with their GA MAP (75.6%, SD=24.3), but this result was not statistically significant (p=0.078). For this condition, four participants (P2, P4, P5 and P6) performed better with their original MAP while one (P1) performed better with their GA MAP and two performed equally with both MAPs (P3 and P7).

%-Correct	Male Sung Vowel		Female Sung Vowel		Combined (Male + Female)	
Participant	Original	GA	Original	GA	Original	GA
1	91.7	83.3	87.5	100	89.6	91.7
2	87.5	87.5	100	75.0	93.8	81.3
3	87.5	95.8	91.7	91.7	89.6	93.8
4	87.5	79.2	66.7	50.0	77.1	64.6
5	62.5	62.5	87.5	37.5	75.0	50.0
6	95.8	75.0	91.7	75.0	93.8	75.0
7	100	100	100	100	100	100
Mean	87.5	83.3	89.3	75.6	88.4	79.5

Table 15: Comparison of original and GA MAP scores for half-octave interval pitch ranking task (male and female sung vowels)

When combining the scores for the male and female conditions it can be seen that, as a group, the participants were more accurate with their original MAP (88.4%, SD=11.1) than with their GA MAP (79.5%, SD=19.0) (Figure 22). This difference was statistically significant (p=0.044). Four participants (P2, P4, P5 and P6) performed better with their original MAP, while two (P1 and P3) performed better with their GA MAP, and one (P7) scored 100% with both MAPs.

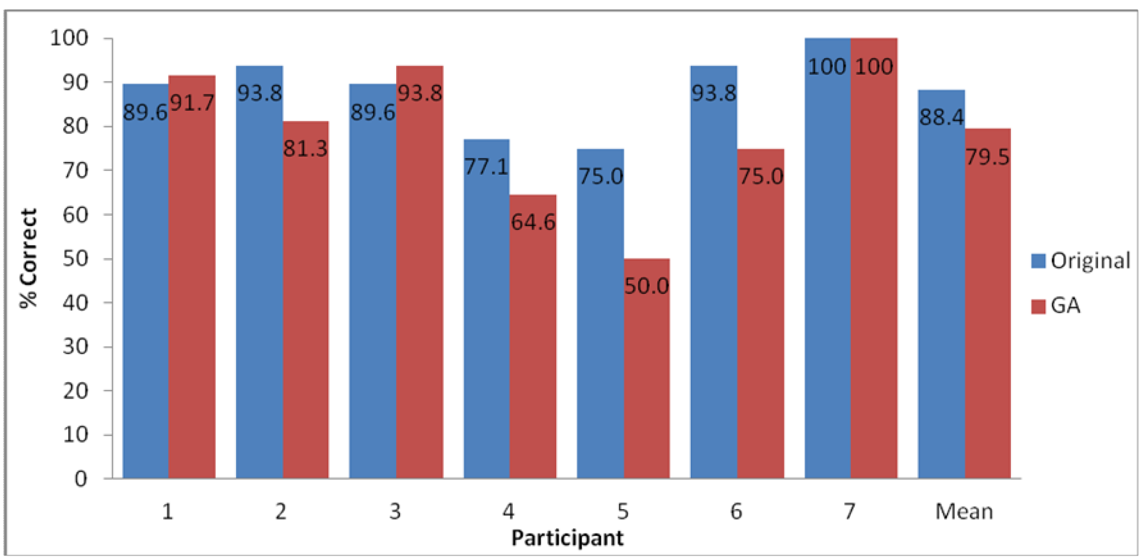

Figure 22: Comparison of average (male and female) original and GA MAP scores for pitch ranking task (half octave interval)

Quarter-octave interval

Table 16 provides the individual participants' results for this subtest. As a group, for the male-sung vowel, participants' scores were very similar for the GA MAP (76.8%, SD=18.2) and the original MAP (76.3%, SD=12.2), with statistical analysis revealing that this difference was not significant (p=1.000). It can be seen that three participants (P4, P5 and P7) scored higher with their original MAP, three (P1, P3 and P6) scored higher with their GA MAP, and one (P2) performed the same with each MAP. For the female sung vowel, again GA MAP scores (64.3%, SD=21.3) were slightly higher than original MAP scores (61.6%, SD=18.4), but with no significant difference (p=0.674). Three participants (P1, P3 and P6) scored higher with their GA MAP, while three (P2, P4, P5) performed better with their original MAP and one (7) scored 100% with both MAPs

%-Correct	Male Sung Vowel		Female Sung Vowel		Combined (Male + Female)	
Participant	Original	GA	Original	GA	Original	GA
1	75.0	87.5	53.1	62.5	64.1	75.0
2	78.1	78.1	65.6	56.3	71.9	67.2
3	81.3	93.8	59.4	84.4	70.3	89.1
4	62.5	56.3	43.8	37.5	53.1	46.9
5	65.6	50.0	50.0	46.9	57.8	48.4
6	71.9	75.0	59.4	62.5	65.6	68.8
7	100	96.9	100	100	100	98.4
Mean	76.3	76.8	61.6	64.3	69.0	70.5

Table 16: Comparison of original and GA MAP scores for quarter-octave interval pitch ranking task (male and female sung vowels)

When combining the scores for the male and female conditions it can be seen that, as a group, scores for the two MAPs were very similar (GA MAP: 70.5%, SD=20.1, original MAP: 69.0%, SD=16.8) (Figure 23), and not significantly different (p=0.694). Four participants (P2, P4, P5 and P7) performed better on this task with their original MAP, while three participants (P1, P3 and P6) were better with their GA MAP.

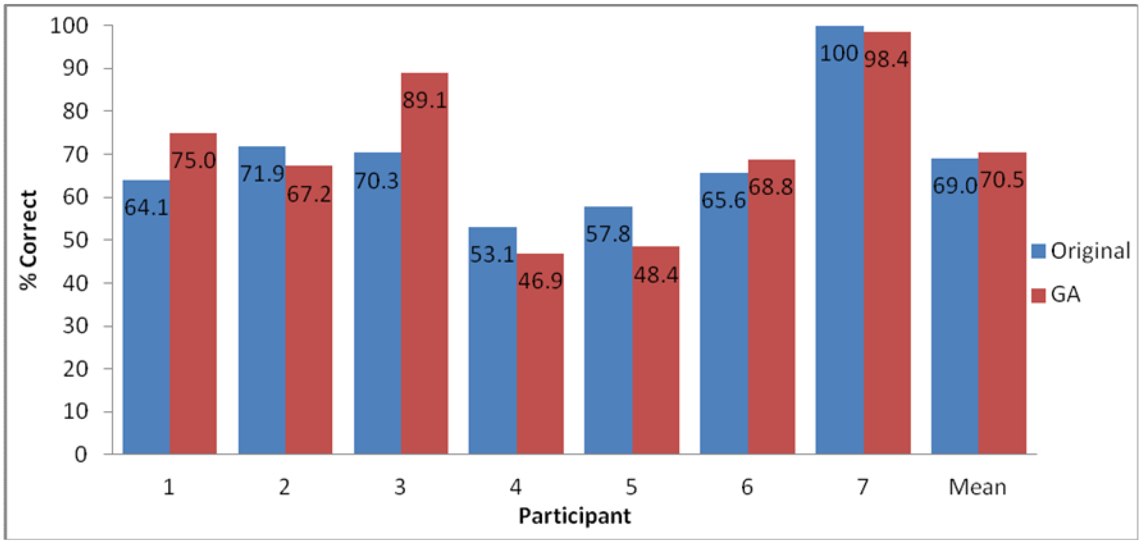

Figure 23: Comparison of average (male and female) original and GA MAP scores for combined pitch ranking task (quarter octave interval)

Correlations between pitch task scores and subject variables

Pearson's R correlations were calculated to assess for associations between individual participant factors and performance on the pitch ranking tasks. A list of correlations can be seen in Table 17. The following significant positive correlations were found between the pre-hearing loss listening score and:

- Performance on the full-octave interval task with the GA MAP (p=0.013)
- Performance on the half-octave interval task with the original MAP (p=0.021).

Participant Factor	Full Octave		Half Octave		Quarter Octave	
	Original	GA	Original	GA	Original	GA
Sex	-0.180 p=0.699	-0.698 p=0.081	-0.710 p=0.074	-0.224 p=0.629	-0.160 p=0.732	-0.186 p=0.690
Age	0.517 p=0.234	0.561 p=0.190	0.511 p=0.242	0.024 p=0.959	-0.083 p=0.860	-0.049 p=0.917
Time with cochlear implant	0.162 p=0.728	0.090 p=0.847	0.062 p=0.894	0.595 p=0.158	0.347 p=0.446	0.416 p=0.353
Duration of profound hearing loss pre-implant	0.338 p=0.459	0.091 p=0.846	0.175 p=0.707	-0.413 p=0.358	-0.262 p=0.571	-0.042 p=0.928
Music experience score	-0.031 p=0.948	0.231 p=0.617	0.466 p=0.292	0.393 p=0.383	0.564 p=0.188	0.367 p=0.418
Pre-hearing loss listening score	0.487 p=0.268	0.860* p=0.013	0.831* p=0.021	0.608 p=0.147	0.359 p=0.428	0.416 p=0.353
Post-implant listening score	0.540 p=0.211	0.310 p=0.499	0.343 p=0.451	-0.203 p=0.662	-0.267 p=0.562	0.077 p=0.870

Table 17: Matrix of correlations between participant factors and performance on the pitch ranking task

* = p <0.05

3-4-4. Correlations between MTB subtests

Pearson's R correlations were also calculated to determine if there were any correlations between performance on the different MTB tasks. These are reported in Table 18. The following significant positive correlations were found between performance on the MTB tasks when using the GA and original MAPs:

- Single instrument identification task (GA MAP) and ensemble identification task (Original MAP) (R=0.806, p=0.028)
- Single instrument identification task (GA MAP) and ensemble identification task (GA MAP) (R=0.919, p=0.003)
- Single instrument identification task (Original MAP) and ensemble identification task (GA MAP) (R=0.880, p=0.009)
- Ensemble identification task (GA MAP) and ensemble identification task (Original MAP) (R=0.879, p=0.009)
- Melody identification task (GA MAP) and melody identification task (Original MAP) (R=0.827, p=0.022)

- Combined pitch ranking task (GA MAP) and combined pitch ranking task (Original MAP) (R=0.607, p<0.001)

Task		Single Instrument		Ensemble		Melody		Pitch
		Original	GA	Original	GA	Original	GA	Original
Single Instrument	GA	0.741 (p=0.057)						
Ensemble	Original	0.642 (p=0.120)	0.806* (p=0.028)					
	GA	0.880* (p=0.009)	0.919* (P=0.003)	0.879* (p=0.009)				
Melody	Original	0.403 (p=0.371)	0.347 (p=0.446)	0.367 (p=0.446)	0.320 (p=0.483)			
	GA	0.396 (p=0.379)	0.685 (p=0.089)	0.536 (p=0.215)	0.530 (p=0.221)	0.827* (p=0.022)		
Pitch	Original	0.560 (p=0.191)	0.211 (p=0.650)	-0.233 (p=0.614)	0.230 (p=0.620)	0.082 (p=0.861)	0.038 (p=0.935)	
	GA	0.539 (p=0.211)	0.498 (p=0.256)	0.201 P=0.666	0.510 (p=0.242)	0.493 (p=0.261)	0.638 (p=0.123)	0.607* (p<0.01)

Table 18: Table of correlations between performance on the Music Test Battery

* = p <0.05

3-5. Listening Diary Ratings

Each participant compared their GA MAP to their everyday MAP for a range of listening situations using visual analogue scales in their listening diary. Participants rated the MAPs in terms of which sounded more natural, more pleasant, and which was better in each situation. These ratings were then converted to a numerical score by measuring the distance of the rating from the neutral, middle position. A positive rating (i.e. a mark on the right hand side of the midpoint) meant that participants preferred the GA MAP, while a negative rating (i.e. a mark on the left side of the midpoint) meant that the original MAP was preferred. It should be pointed out that participants were not explicitly told what situations they should record, or how many situations to record. Hence the range of types and numbers of listening situations reported on varied from one participant to the next. Statistical analysis to compare the different environments was not possible as some participants rated several different situations in the same environment. Furthermore, some environments had only one or two respondents.

From the 58 listening situations reported on, these were broadly classified into 7 listening environments according to the primary purpose of the individual being in that environment. The environments were social situations with noise; watching television; listening to music; using the telephone; driving; quieter social situations; and at the movies. The average participant ratings across the seven broad listening environments are shown in Figure 24. A positive rating indicates that the GA MAP was preferred for a listening situation and a negative rating indicates that the original MAP was preferred. The height of the column indicates the degree of preference. The results show that the GA MAP was only rated as more pleasant for watching movies (average rating = 4.05). The group results also show that the GA MAP was rated as "better" for both watching movies (average rating=4.75) and listening to music (average rating= 0.44). Participants rated their original MAP as much better for listening in noise (pleasant= -5.78, natural= -6.07, better= -5.12) as well as in quiet (pleasant= -6.95, natural= -6.65, better= -6.65) than their GA MAP.

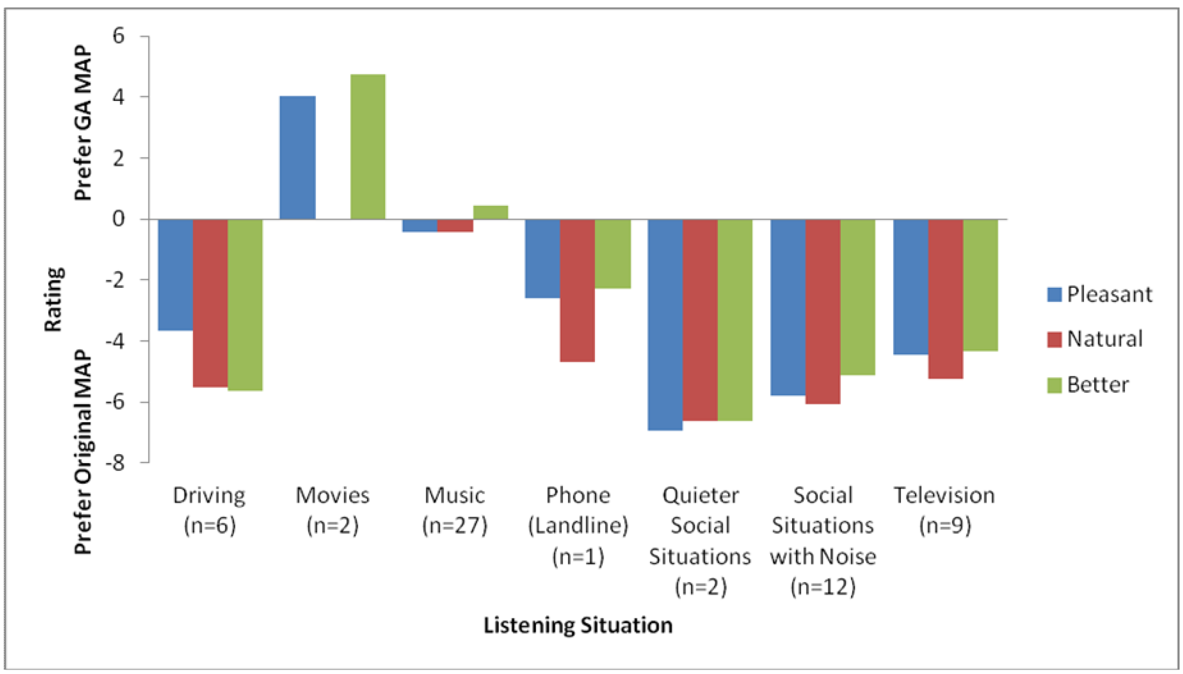

Figure 24: Average ratings of whether the original or GA MAP is more pleasant, natural, and better across different listening environments

A positive rating indicates that the GA MAP was preferred for that listening situation, whilst a negative rating indicates that the original MAP was preferred.
'n' refers to the number of times this listening environment was reported by all participants in their listening diaries

3-6. GA FITTING QUESTIONNAIRE

Participants completed a 12 item questionnaire on the GA Fitting software and procedure with responses provided on a 3-point scale (Appendix B). The participants' responses to the GA Fitting Questionnaire are summarised in Figure 25. The results show that six participants were excited about creating a custom program, and that five found the procedure to be fun/enjoyable. Further to this, four participants preferred the GA fitting to a traditional MAPping procedure, six liked the freedom to work at their own pace, while five participants reported liking that they were in control of creating their own program. Six participants reported that clinics should offer an approach like this, with four saying that this would increase their motivation to attend their clinic. Four participants reported that they would like to use the software to customise programs for other listening situations. Six participants reported that they would use this software on their home computer, with responses being mixed as to whether clinical supervision was necessary, and only one participant reporting concerns about a customisation session taking too long.

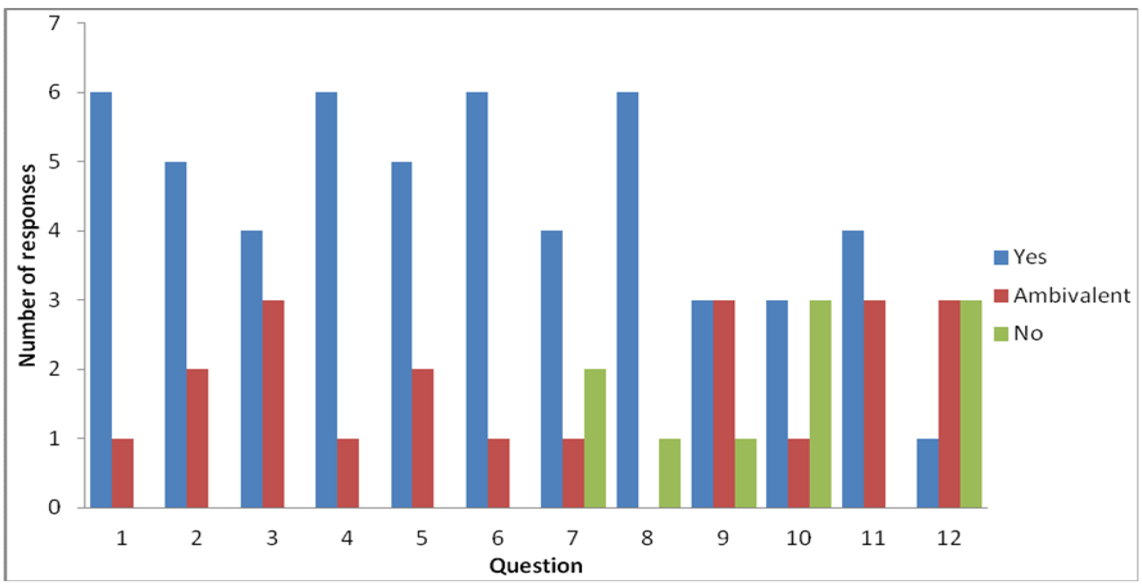

Figure 25: Participant response to the Genetic Algorithm Fitting Software Questionnaire

For the purpose of this study, ambivalent was defined as "no strong opinion either way".

Legend

1: Were you excited about creating a custom music program?
2: Was the procedure fun/enjoyable?
3: Did you prefer it to a traditional procedure?
4: Did you like the freedom to work at your own pace?
5: Did you like being in control of creating your own program?
6: Should clinics offer an approach like this?
7: If so, would you be more motivated to visit your clinic?
8: Would you use software like this on your home computer?
9: What about on a hand-held device (e.g. Remote control)?
10: Would you feel confident customising your program without clinical supervision?
11: Would you like to use it to customise programs for other listening situations (television, restaurants, movies, church, etc)?
12: Do you have concerns about a customisation session taking too long?

Overall, the only statistically significant differences between the GA and original MAPs were that participants scored higher with their GA MAP for the melody identification task, and with their original MAP for the half-octave (combined) pitch-ranking task. The ratings from the listening diary indicated that participants preferred their original MAP for most situations except the movies (for which they rated the GA MAP to be more pleasant and better overall) and for music (for which they found the GA MAP to be better overall).

4. Discussion

The aim of this study was to assess the appropriateness of using a GA to create a MAP specifically for music appreciation (GA MAP). It was expected that participants would perform better on tasks of timbre, melody and pitch perception when using their GA MAP compared to their original MAP. It was also expected that participants would prefer the GA MAP for situations where music listening was the primary goal. However the averaged group results showed that the only task where participants performed significantly better with the GA MAP was on the melody identification task. For the half-octave pitch ranking tasks, performance was significantly better with the original MAP. The ratings from the listening diary showed that, although participants preferred their everyday MAP for most situations they encountered, there was a small preference for their GA MAP for situations where music listening was the primary purpose, and a large preference when at the movies.

This chapter will begin by comparing the original and GA MAPs parameters, along with participants' performance with these two MAPs on speech tests, the MTB and the listening diary. This is followed by a discussion of the clinical implications of the study's results, followed by consideration of the limitations of the research, and areas for future research.

4-1. Comparison of the Original and GA MAPs

4-1-1. GA MAP Characteristics

Using the GA software, all participants created a MAP for music listening that had 12 maxima. For six of these participants, this was an increase in the number of maxima from their original MAP (8 maxima), while for the other, this was the same number of maxima as their original MAP. Currently no studies have looked specifically at the number of maxima required for music perception and enjoyment. However, Plant et al. (2002) investigated the effect of different maxima (6, 8, 12 or 16) on the speech perception abilities of eight post-lingually deafened Nucleus CI24M users. Overall, participants had significantly poorer recognition of open-set monosyllabic words when using 16 maxima compared to 8 maxima and significantly lower recognition for open-sentences in competing noise when using 6 maxima compared to any other condition. From these results, Plant et al. (2002) concluded that 8 or 12 maxima should be selected when programming the ACE strategy for speech perception. Similar results were found by Stieler & Obrebowska (2008).

These studies have focussed on speech perception; however music is a much more complex stimulus requiring a greater number of channels for accurate perception, even when compared to the perception of speech in noise. Smith et al. (2002) assessed 6 NH participants on their ability to recognise melodies and speech when the signal envelope was presented through increasing numbers of frequency bands (1-64). The frequency bands spanned 80-8820 Hz and were logarithmically spaced to mimic the tonotopic organisation of the cochlea. The stimuli consisted of familiar melodies devoid of rhythmic information, and sentences presented in noise. The results showed that speech reception was above 80% with 8 frequency bands (channels). However, melody recognition required a greater number of frequency bands for participants to score similarly with 48 channels required for greater than 90% recognition. This may be due to the potential that melody recognition requires greater spectral specificity which is only available with having smaller frequency bandwidths that result from having a greater number of channels.

It is important to note that in this study the GA software parameters had an upper limit of 12 maxima. Given that this is lower than the number of channels in the Smith et al. (2002) study, it is possible that the optimal number of maxima for music listening may be higher than this. Further, in the ACE processing strategy CI users can have up to 22 channels, of which there is a limit of 20 maxima. This is considerably less than the number of channels required for accurate melody identification as reported in the Smith et al. (2002) study, suggesting that the performance of CI users is at least partly restricted by the limitations of the implant itself.

GA MAPs in the current study had stimulation rates of 500 Hz, 900 Hz or 1200 Hz. Six participants created a GA MAP with a 900 Hz stimulation rate, while one participant created a GA MAP with a 500 Hz stimulation rate. For three participants this was a different stimulation rate to their original MAP. At present there are no studies on the preferred stimulation rate for music perception and enjoyment. However, this preference for a stimulation rate of 900 Hz and 500 Hz is consistent with studies that have investigated preferential stimulation rate for speech perception (Arora et al., 2009; Skinner et al., 2002). Skinner et al. (2002) looked at the performance and preference of 62 Nucleus 24 CI recipients using the ACE, CIS and SPEAK processing strategies. The results showed that the majority of participants who used the ACE strategy preferred a stimulation rate between 500 Hz and 900 Hz. One reason for this may be that CI users are unable to use the extra information that is available with higher stimulation rates and/or find the extra information 'confusing'.

Current Nucleus CIs have several optional sound processing features to assist with listening in more complex environments such as noise and for music. These are BEAM™, Automatic Sensitivity Control (ASC), Whisper™ and Adaptive Dynamic Range Optimisation (ADRO™). Each of these features adjusts the signal in different ways to try and improve the way that CI users perceive a signal and are discussed in further detail below.

Of the sound processing features available in current Nucleus Freedom processors, BEAM™ and ASC were intended to improve performance in noise. In the current study, no participants had a MAP (GA or original) that used BEAM™. ASC is designed to reduce the effect of noise on a signal by automatically adjusting the microphone sensitivity based on the level of the noise floor in the listening environment. Only one participant used ASC in their original MAP; however they did not report any comparisons of their two MAPs for situations where the primary purpose was listening in noise. Only one participant used ASC in their GA MAP; however they preferred their original MAP for the one situation where they reported listening in background noise. As part of their study, Wolfe et al. (2009) demonstrated the usefulness of ASC for improving speech perception in noise for 10 adult CI Nucleus Freedom recipients using the ACE and SPEAK strategies. Participants were assessed on HINT sentences with and without ASC at four SNRs (quiet, +10 dB, +7 dB, and +4 dB). The results showed that as a group, participants performed significantly better with ASC when the SNR was +7 dB and +4 dB, but there was no significant difference in the quiet and +10 dB conditions.

In general, for situations involving noise, participants tended to rate their original MAP as more pleasant, more natural, and better. However, given that no MAPs contained BEAM™ and only P6's GA MAP and P3's original MAP contained ASC, the preference for the original MAP in noisy situations may be due to the presence of Whisper™ in the GA MAP for the majority of participants. This feature was absent in all participants' original MAPs. Whisper™ is designed to improve the perception of soft speech by increasing the levels of low-input signals. While beneficial in quiet situations, this feature may present a problem in background noise as it would also increase the level of background noise, consequently decreasing the SNR. This may have led to the four participants (P1, P2, P5 and P7) who had this feature in their GA MAP, rating their original MAP as better for listening in background noise.

While Whisper™ may have influenced the poorer ratings of the GA MAP in noisy situations, it may have also contributed to the preference of the GA MAP for music listening for P1 and P7. As MAPs with this feature provide more information on low-intensity sounds, it could increase CI users' access to the softer components of music, providing the implant user with more information.

The one feature that was common to all MAPs (GA and original) was ADRO™. ADRO™ adjusts the gain independently in each channel, based on the input level and background noise for each channel. It aims to avoid loudness discomfort while increasing the audibility of soft sounds (Dawson et al., 2004). Dawson et al. (2004) demonstrated a significant improvement of sentence perception scores in quiet (8.60%) and in noise (6.87%) for 15 child SPrint CI users when using ADRO™. Similar results were found by James et al. (2002).

4-1-2. Speech Perception

As a group, there was no significant difference between the original and GA MAPs for speech perception in quiet (99% and 89% respectively). This lack of significant difference is at least in part attributable to a ceiling effect. In the current study, two participants scored 100% with both the original and GA MAPs, and all participants scored at least 96% with their original MAP. This means that the magnitude of difference between the MAPs would have been masked by the high original MAP scores. This ceiling effect has been reported for the HINT sentence material. Although this was the test used by the clinic involved in this study, a recent study by Gifford et al. (2008) showed that the HINT sentences are not the most appropriate measure of open-set speech recognition in quiet for CI recipients. Gifford et al. (2008) assessed 115 postlingually deafened unilateral CI users on speech recognition in quiet (using the HINT sentences, the AzBio sentences, and the CNC words test). They found that of the 115 unilateral CI users assessed on the HINT sentences, 30 (26.09%) scored 100%, with the mean score being 84.8% correct. This was much higher than for the AzBio sentences and the CNC words in quiet, which were normally distributed and had no ceiling effects. The authors also found that scores on HINT sentences was much higher than performance on the CNC words test, while performance on AzBio sentences were less variable compared to the CNC words test. From their research, the authors concluded that the HINT sentence material was too easy and not appropriate to assess CI user's speech perception in quiet unless it was used in its original adaptive format. Similar results for children were found by Looi & Radford (in press)

It is interesting to note that the results obtained in the current study, with both MAPs, were higher than those obtained in some previous studies where participants used the ACE processing strategy. For example, Balkany et al. (2007) assessed the speech perception abilities of 55 post-lingually deafened adult Nucleus Freedom recipients using the HINT sentences in quiet. The mean score for their participants was 78% correct, which was lower than the average score obtained from our participants when using either MAP. This was despite the 55 participants in the Balkany et al. (2007) study having had at least six months experience with their MAP, while participants in this study only had one month's experience with their GA MAP. More recently, Bradley et al. (2010) reported the post-implant HINT scores of patients in SCIP-A, which was the program involved in this study. Their retrospective analysis of patients implanted between 1999 and 2008 revealed that the mean post-implant HINT scores (auditory alone) at nine months was 74% (n=78); by 18 months this increased to 81% (n=52).

Overall, the participants in this study appear to perform better on the HINT than the average implant recipient. This may have meant that the participants in this study were 'high performers' and thus more likely to perform better with the GA MAP. The implications of this for the current research will be discussed later.

4-1-3. MUSIC TEST BATTERY

The results showed that participants performed significantly better on the half-octave interval pitch ranking task with their original MAP and on the melody identification task with their

GA MAP. There was no significant difference between the MAPs for the two timbre identification tasks. The higher melody identification score with the GA MAP may have been due to the learning effect as testing with the GA MAP was the second time participants had undertaken the melody test. Due to the timing and logistical restrictions of the study, the order of MAP testing could not be randomised, nor could a different experimental design be adapted that would have accounted for a learning effect (e.g. an A-B-A-B design). A similar effect was found by Looi et al. (2008) whose participants scored higher on the melody test during the second testing session (mean score = 54.7% correct) than the first (mean score= 49.0% correct). Although the difference in Looi et al.'s (2008) study was not significant, the current study used fewer participants, a condensed version of the test, fewer stimuli, and less time between testing sessions. This learning effect may have been less of a factor in the two timbre tests which used more stimuli (12 versus 8), and had more presentations of each stimuli (4 versus 2), meaning that for the timbre identification tasks, participants had 48 presentations per test, as opposed to 16 for the melody identification task. This may have meant that participants had a better chance of remembering stimuli from the first testing session.

The lack of significant difference in timbre identification scores with the two MAPs may be explained by the limitations associated with current implants (i.e. the number of available channels, fixed stimulation rate, spatial specificity as discussed in the Introduction). These limitations would have been inherent to both the original and GA MAPs, and as a result the GA MAP may not have provided significant extra information to assist with music listening. Another explanation is that the GA process was based on optimising the ACE strategy, which is a strategy designed for speech perception. As a consequence, there may be limitations with the strategy (e.g. fixed stimulation rate, number of maxima) that inhibit any extra information from being perceived by the recipient. Furthermore, if participants had greater acclimatisation time with the GA MAP then their GA scores may have been better than those obtained with the current study's procedure. The effect of acclimatisation will be discussed in the limitations section.

While performance on the timbre identification tasks with the original and GA MAPs were not significant, there were significant differences between scores on the two identification tasks. This is consistent with current literature suggesting that the complexity of stimuli can affect music listening. Leal et al. (2003) investigated the ability of 29 adult Nucleus CI24 users to recognise 7-8 familiar songs. They found that when melodies were played by an orchestra with no verbal cues, only one participant correctly identified at least 50% of the songs. However, when the songs were played on the piano, 14 participants correctly identified at least 50% of the songs, and when the songs were played by an orchestra with verbal cues, 28 of the 29 participants correctly identified at least 50% of the songs. This both suggests that single instruments may be easier for implant users to follow than an orchestra, and that the inclusion of words/lyrics resulted in the best performance. In the current study, participants performed, on average, better in the single instrument identification task than the ensemble identification task regardless of which MAP they used.

As a group, participants involved with this study performed better on the MTB than participants in previous studies using the same tests, such as those in Looi et al.'s (2008) study (n=15). The trend was observed for all tasks except for the ensemble task, regardless of whether participants used their original or GA MAP. Participants in this study also scored higher on speech perception tasks (original MAP mean= 99%, range=96-100%) than those in the Looi et al. (2008) study (mean= 83.9%, range 37-100%). An independent samples t-test revealed that this difference was significant (p=0.031). This implies that the participants in the current study were a higher performing group, and subsequently may have been able to better utilise the cues available to them through their implant.

While the participants, as a group, performed well on the MTB, there was considerable inter-subject variability. For example, when using the GA MAP on the ensemble identification task, P5 scored 14.6% while P7 scored 91.7%. The range of participant scores for all tests is reported in Table 5 (page 33). This high inter-subject variability is consistent with previous studies that have found that whilst some CI users perform well on music perception tasks, others perform poorly (e.g. Looi, 2008; McDermott, 2004).

For both the melody and pitch tasks, there were significant positive correlations found between performances with the two MAPs, implying that participants who performed well with one MAP were likely to perform well with the other MAP on the same task. Further, performance on the single instrument identification task with the GA MAP was consistent with performance on the ensemble identification tasks, and high performers on the ensemble identification task with their GA MAP were more likely to have performed well on both instrument identification tasks with their original MAP. This suggests that the limitations associated with music perception for CI recipients is not 'solved' by the GA-approach; i.e. it is probably not the solution to improve perceptual accuracy for music. However, as will be discussed in the next section, participants tended to subjectively prefer the GA MAP for situations involving music listening. Perceptual accuracy and music appreciation are two different issues and although may be related, they are not 'one and the same'. For example being able to name or recognise a piece of music does not mean that one may like or appreciate it; and similarly one does not need to know a piece to enjoy it (e.g. Gfeller et al., 1998; Looi et al., 2007).

There were also significant positive correlations between the participants' pre-hearing loss listening scores and their performance on: (i) the full-octave interval pitch ranking task when using their GA MAP, and (ii) the half-octave interval pitch ranking task when using their original MAP. This is somewhat consistent with previous studies (e.g. Gfeller et al., 2008) who found that high school/adult music training was a significant predictor of a recipient's performance on a pitch ranking task, along with a range of other music perception tasks. One reason for the lack of similar correlations in the current study is that our pre-hearing loss listening score was derived from a number of factors which were not found to be significant predictors in the Gfeller et al.'s (2008) study (i.e. time spent listening to music, enjoyment of music, and training at primary school), as opposed to just evaluating high school/adult music training.

4-1-4. Listening Diary Ratings

The responses from the listening diary indicated that participants preferred their GA MAP for music listening and when at the movies. Keeping in mind that the purpose of this study was for participants to create a MAP specifically for music, it would appear that this MAP was appreciated by most participants for the situation for which it was created.

The difference between the GA and original MAP was very small (i.e. the preference for the GA MAP for music was overall less than 1), one reason for this is that the participants in this study used the ACE processing strategy which was designed for speech perception, not music perception. As a result, the GA MAP created for this study was based on a speech processing strategy, but the MAP was optimised for music. Hence the GA MAP may not be the most optimal MAP for music listening as the features required for accurate speech perception are different to those required for music perception and enjoyment.

4-2. Clinical Applications

4-2-1. The GA Fitting Process

A questionnaire was administered post-fitting to find out about participants' attitude towards, and experience with, the GA fitting process. In general, participants were positive about the GA fitting process; six participants reported that they had been excited about creating a custom music program, and no participant found the process unpleasant. Participants reported that they enjoyed being able to work at their own pace and having the control to create their own MAP. These are important considerations as the process of finding an optimal MAP is not always straight forward, and making the process more enjoyable and individualised may lead to higher levels of intrinsic motivation for patients. Motivation is considered intrinsic if it results from the enjoyment and/or satisfaction associated with a task, and extrinsic if it results from the rewards or punishments associated with task success (Lin et al., 2001). Lin et al. (2001) demonstrated the importance of intrinsic motivation to success in 650 university students. They found that high levels of intrinsic motivation were positively related to success (higher grades). In terms of creating the optimal MAP for music listening, higher levels of intrinsic motivation may mean that participants are more likely to persevere with the search for an optimal MAP, and with the MAP itself.

No participant was opposed to clinics offering the GA approach to MAPping, and two participants stated that they would be more motivated to visit their clinic if this procedure was available. In addition, all participants were open to using this approach to customise programs for other listening situations. Six reported that they would like this software available on their home computer while three would like this software available on a hand-held device. These results suggest that participants are interested in taking more ownership for their MAPs, and to create their own MAPs for different listening situations important to them.

Interestingly, three participants reported that they would not feel confident about customising their own MAP without supervision from an audiologist. When interpreted with the above responses that they would like the software available to them outside the clinic, it would seem that some participants would only be comfortable using it after training from their audiologist and/or would still want the support of their audiologists should any problems arise.

Evidence from this study suggests that a follow-up appointment may be beneficial to process of fitting a GA MAP. In this study, some participants had one or two complaints that they felt stopped the GA MAP from being useful. It is possible that these complaints may have been resolved at a follow-up appointment.

The greatest barrier to the efficiency of the GA process was that participants were unable to hear through their implant when they were not listening through one of the GA MAPs. This was particularly challenging during the first few sets of GA MAPs when participants were seeking clarification and reassurance that they were doing the task correctly and were unable to hear the feedback. One solution to this may be to add a "Listen through MAP" option that allows the user to hear through their everyday MAP. The efficiency of the program was also limited by the delay that occurred between clicking on a MAP to listen through it, and the time it took for the MAP to activate in their speech processor. While this delay was approximately 5 seconds, this meant that participants who listened to all MAPs were adding an extra 40 seconds of listening time to each generation of MAPs. Based on the average number of generations for participants in this study, this would have added to an extra 11 minutes and 4 seconds.

4-2-2. Benefits for clinicians

In recent years there has been increasing research on methods to improve the MAPping process (Caner et al., 2007; Jethanamest et al., 2010; Potts et al., 2007), in particular to try to improve the efficiency of the process. Plant et al. (2005) investigated a streamlined approach to MAPping for 16 postlingually deafened Nucleus CI recipients. As part of their experiment, the authors measured the T and C levels on three electrodes (most basal, most apical and electrode 10) and then interpolated these measurements to all other electrodes. Participants were asked to compare this MAP with their traditionally obtained MAP and were assessed on a speech perception test. There was no significant difference in speech perception scores with the two MAPs, and 81% of participants either preferred the streamlined MAP or had no preference for either MAP. . In another study, Wesarg et al. (2010) investigated the potential of a remote approach to MAPping in 70 adult Nucleus CI users. Participants were MAPped both using the traditional (face-to-face) approach as well as remotely from a separate location via an internet connection and video conference software; feedback was sought regarding this process. All but one participant could be MAPped with both methods and there was no difference in the T- and C-levels between the two approaches (except for electrode 17 where the T difference was -1). Furthermore, both implantees and clinicians responded positively to the process. The current research adds to these studies by investigating another way to improve the efficiency of the MAPping process.

While only two of the participants (P3 and P7) decided to keep their GA MAP after the study had finished, P1 reported that their GA MAP was "good for music" and that they were "picking up a lot more detail" when compared to their original MAP. However, he felt that the new MAP was not different enough to warrant keeping, but had he not had his original MAP, he would have been happy with the GA MAP. Two participants (P2 and P6) did not report using their GA MAP specifically for music and for the remaining two participants (P4 and P5), the main complaint was that their GA MAP was "too confusing" and that it "may just be because [they were] used to program one" (P5), and that the new program had a "tinny sound" which was "odd" (P4). These complaints suggest that an acclimatisation period may be necessary when receiving a new MAP. Comments such as 'tinny' or 'odd sound' and 'not being used to it' are common responses to new MAPs and/or at the initial stimulation of the CI. However, after some time, as the brain adjusts, patients often find the sounds become more natural and 'normal'. These participants may have benefited from a follow-up session to address their complaints where further minor adjustments could have been made to the new GA MAP. However due to logistical constraints, this was not feasible in the current study.

At present, finding an optimal MAP for a client can take many sessions as there are a great number of parameter combinations, which must be trialled one at a time for comparison. The average fitting time for participants in this study was 35 minutes, which is a clinically appropriate duration. Furthermore, participants converged on a GA MAP after an average of 16.6 generations (or having been presented with 133 MAPs in sets of 8). Only one participant's GA MAP was the result of a forced convergence (i.e. they were unable to decide which MAP sounded better). Interestingly, this participant gave up on their MAP partway through the study, whether this suggests that a GA MAP that results from a forced-convergence is of less benefit would be a topic for future research.

The advantage of using a GA approach is that a useful custom MAP for music listening can be created after one session, and that patients could efficiently create several MAPs for different listening situations applicable to them. This has the potential to free up clinician time by reducing the number of appointments required to adjust a MAP for different listening situations. Further to this, once a client is trained on the software, follow-up appointments could be done without the direct supervision of a clinician, further freeing up clinician time.

This approach may also benefit clients who have greater trouble finding MAPs that are suitable to their listening needs. It allows the implant recipient to search through a large number of MAPs in a relatively short amount of time, and, even if clients are unable to find the optimal MAP, the process may help them to find several suitable MAPs. The clinician can then analyse the parameters of these MAPs to determine how to best fine-tune the recipient's MAP.

The software could also be used to efficiently create MAPs that are customised for specific listening situations the client deems important, or is having difficulty with, by using stimuli that represents the situation (e.g. speech in noise). This allows them to generate a MAP for the situation for which it will be used as opposed to creating a MAP using speech in quiet as the reference. Leading on from this, by comparing the similarities and differences in MAPs created for different situations, the clinicians may be able to get an idea of the parameters that the individual prefers. Thus, when they are creating or fine-tuning future MAPs for that individual, they may have an idea of which parameters are preferred and which could be altered.

4-2-3. Counselling For Music Listening

The results of this study indicate that, regardless of which MAP the participants used, there were limitations to their perception of timbre, pitch and melody. Common comments were that music sounded less sharp (P3), and that the "instruments [were] more muted" (P4) than the GA MAP. This is consistent with current studies that have shown decreased appreciation and perception of music post-implant compared to pre-hearing loss (e.g. Looi et al., 2007; McDermott, 2004). This indicates the importance of counselling candidates pre-implantation as to realistic expectations of their ability to perceive music post-implantation. Candidates should be aware that music perception may be more limited post-implantation and that they are unlikely to perceive music as well as they did pre-deafness. However there is evidence to suggest that the perception of music post-implant is better compared to their pre-implant HA use (Looi et al., 2007), and that music perception can be improved with focused music training.

The benefit of music training can be seen in the perceptual abilities of P7. P7 had the most music listening experience pre-deafness of all participants, having studied the violin, piano and music at University. He had also been a professional soloist prior to his hearing loss. Furthermore, since implantation, P7 reported that he had tried to improve his music perception ability through much focused listening practice, self-training and investing of lot of time trying to enjoy music with the implant. The effect of this can be seen in P7's scores on the MTB, which were consistently higher than the other participants in this study. Table 19 shows P7's results on the MTB compared to the mean of the other six participants. Further to this, P7 was the only participant to score the same or higher on almost all MTB tasks with their GA MAP than with their original MAP (with the exception of the quarter-octave pitch-ranking task, where P7 scored 98.4% with their GA MAP and 100% with their original MAP). Given this participant's high scores on the MTB, and success with the GA MAP, it may be that those with more musical experience are better able to perceive the differences between the two MAPs, than those with less musical experience.

In addition to this, the difference between the group's performance on the single instrument and ensemble identification tasks should be taken into account when participants are relearning to listen to music with their implant. Participants in this study were more accurate on the single instrument identification task, implying that new recipients may be better to begin with simple stimuli when they first start listening to music through their implant. This finding occurred regardless of which MAP participants used, and is consistent with reports from other studies (Looi et al., 2008; Looi & She, 2010).

Task	Original MAP		GA MAP	
	P7	P1-6 Mean	P7	P1-6 Mean
Single Instrument Identification	98	69	98	65
Ensemble Identification	79	45	92	32
Melody Identification	88	77	100	85
Pitch Ranking One-Octave Interval	94	97	98	84
Pitch Ranking Half-Octave Interval	100	86	100	76
Pitch Ranking Quarter-Octave Interval	100	64	98	66

Table 3: Comparison of Participant 7's scores on the MTB with the average scores of the other 6 participants (%-correct scores)

The results also suggest that musical pieces containing lyrics, as opposed to instrumental pieces, may be easier to follow. This could be because the lyrics are easier for and/or more accurately perceived by the recipient, hence they provide additional cues which aid in identification. This would make intuitive sense given that speech processing strategies are designed for speech and that most CI recipients achieve better speech perception than music perception scores. This result is consistent with that of Looi and She (2010) who surveyed 100 adult implant recipients using the ACE strategy on their music listening habits and enjoyment. Their results showed that 45% of respondents felt that the presence of lyrics helped to improve their music listening enjoyment, and that the majority of respondents felt that the absence of lyrics was detrimental to music listening enjoyment. The importance of lyrics was also demonstrated by Leal et al. (2003) who found that participants were more likely to identify nursery songs when verbal cues (i.e. lyrics) were present.

4-2-4. Assessing Speech Perception

As mentioned, all participants in this study obtained high scores on the HINT sentences presented in quiet with their original MAP, suggesting that this material may not be suitable for monitoring speech perception abilities of CI users over time as it may not show subsequent improvements. As recommended by Gifford et al. (2008) if the HINT sentence test is to be used for clinical assessment, it should be administered in an adaptive format, as per the way it was designed. The results also suggest that the production of a New Zealand version of a sentence recognition task with greater validity and difficulty is necessary for clinical use in New Zealand. This is supported by the recent findings of Looi & Radford (in press) who assessed children using cochlear implants and/or hearing aids.

4-3. Limitations and areas for future research

The primary limitation of this study was the length of time that participants spent with their GA MAP prior to testing. Prior evidence has shown that there is an adjustment period when an individual experiences a change to the way they hear sound. For example, Bradley et al. (2010) retrospectively analysed the speech perception scores of 53 CI users at 1, 3, 6, 9 and 18 months post-switch on. They found that speech perception scores improved at each appointment for the first six months, however at the six month follow-up, recipients' scores began to plateau. Further, Vermeire et al. (2009) evaluated the performance of 33 adult TEMPO+ implant users on their perception and subjective evaluation of speech when they changed from the CIS+ to FSP processing strategies. They found that the initial change in strategy resulted in a deterioration of the participant's speech recognition threshold (SRT), however after 12 months of using the new strategy, their SRT had improved significantly. While that study looked at the effect of a new processing strategy, there are currently no studies that specifically investigate the time taken to acclimatise to a new MAP. However, it would seem that at least some period of time needs to be given for adjustment. In the current study, time constraints meant that participants were asked to start comparing their GA MAP to their original MAP from the day that they were given the new GA MAP, with the GA MAP testing conducted approximately 4 weeks later. However, the results from Qi et al.'s (2009) study suggest that this time period may be insufficient for acclimatisation. Qi et al. (2009) assessed the speech perception abilities of MED-EL CI recipients using the CIS and FSP strategies. They found that the switch from one strategy to the other led to an initial decrease in speech perception scores, and that an acclimatisation period greater than 6 weeks was required for CI users to achieve maximum benefit. In terms of the current study, it may be that without a sufficient acclimatisation period, the initial experience with the MAPs may have meant participants were more likely to favour the original MAP as they were more used to it.

Further to this, these previous studies were based on full-time MAP use. In the current study, participants were not required to use their GA MAP full time, and made an average of 8.3 (range 6-19) MAP comparisons in their listening diaries during the four week period with their GA MAP. The average listening time for each of these situations was 80.78 minutes (range 5-360 minutes). This would suggest that participants used their GA MAP for around 11 hours over the four week period, and therefore may not have been able to realise the full benefit of the GA MAP.

Further, despite the GA MAP being created for music listening, participants made the majority of comparisons (54.2%) for situations where music listening was not the primary purpose. In addition to this, two participants (P2 & P6) did not report on the GA MAP for music listening situations. Only P3 and P7 compared the GA and original MAP primarily for music, and interestingly these were the two participants who wanted to keep the GA MAP at the end of the study. Of the remaining participants, P1 compared their MAPs for music listening in one 15-minute situation, P4 for one 60 minute session and a 15 minute session, and P5 for two 30-minute situations. The lack of time spent listening to music with the GA MAP is an important consideration given evidence that exposure to music with an implant is related to better accuracy and appraisal of music (Gfeller et al., 2008). Thus the participants who reported listening to music for minimal amounts of time with their GA MAP throughout this study may not have fully benefited from the new MAP.

Given the evidence about the importance of an acclimatisation period when an implant user receives a new MAP, future research could provide participants with an extended period of time to acclimatise to the GA MAP prior to making comparisons. This may better enable them to realise the full potential of the GA MAP. Alternatively, acclimatisation could be controlled for by creating two MAPs for music in the same session, one using the traditional procedure, and one using the GA software. This would mean that participants were starting from the same point with both MAPs. It would also allow researchers to directly compare the methods for creating a music listening MAP and determine if there was a difference in perceptual performance, appraisal ratings and MAP parameters between the two MAPs. However, if this approach were to be taken then researchers would need to ensure that participants were listening to both MAPs for an equal period of time.

Another limitation was that order of testing of MAPs was not randomised. In this study the GA MAP was always tested second, hence there was a possibility of the better melody identification scores with the GA MAP being due to a learning effect. Future studies without the same time limitations could randomise MAP test order, test participants with both MAPs at both sessions, or use an A-B-A-B design

One option for future studies may be to ask participants to use their GA MAP full-time for a prescribed period of time prior to making comparisons with their original MAP. Having said this, it should be considered that the purpose of the GA MAP generated in this study was for music listening and not for everyday listening. A second option may be to prescribe set periods of time where participants were required to listen to music with their GA MAP. However, the problem with this approach would be that any benefit recorded for the GA MAP for music listening could be attributed to the extra time spent on focused listening practice so it would be unknown whether the benefit for music listening came from the training or the GA MAP itself. A third option would be, as mentioned, to create 2 MAPs for music listening at the same time – one using the GA approach, one using the traditional method. Participants could then use each for a set amount of time over a certain time period before making comparisons.

When interpreting the results of this study it is worth keeping in mind that participants were perceptually able to tell the difference between their original and GA MAPs. After the GA MAPping session, all participants could confidently report which MAP was their original, and which was their GA MAP. It is possible that this could have biased the results obtained, for example if participants felt that they should rate one MAP as better than the other.

A further limitation of this study was the small number of participants; with only seven participants, individual variability would have had a greater effect on the group data analysis. Further, with the results showing that participants scored higher on both the MTB and speech perception tests than those in previous studies (e.g. Balkany et al., 2007; Bradley et al., 2010; Looi et al., 2008), it may be that these participants did not represent the general population of CI users, making it difficult to generalise the findings to the adult CI population in general.

Time constraints meant that this study did not assess quality ratings for music stimuli. The sessions were already long, with the perceptual tests taking approximately 40-60 minutes. Having participants listen to stimuli and rate the sound quality with the two strategies would have meant that another session was required. This would have probably further decreased participant numbers as most participants lived out of town and may have been reluctant to take time out of their schedules for another appointment. However, there is evidence to support the inclusion of such a test as perceptual accuracy and appreciation are separate issues. As part of their study, Looi et al. (2007) looked at the relationship between ratings of timbre quality and the ability of 15 adult Nucleus CI users to identify musical stimuli. They found a significant but weak correlation between timbre recognition and quality ratings (rho= 0.325, p=0.029). This weak correlation supports the idea that the ability to recognise a piece of music is not reflective of one's appreciation of that piece, and vice-versa, and thus should be assessed separately. Furthermore, previous research has shown that CI recipients tend to rate timbre as less pleasant than NH listeners (e.g. Gfeller et al., 1998; Gfeller, Witt, Woodworth et al., 2002) and HA users (e.g. Looi et al., 2007). Looi et al. (in press) developed a music quality rating test battery for cochlear implant recipients that takes approximately 30 minutes to complete. The battery involves participants listening to ten musical pieces and then rating the sound quality using scales of: unpleasant/pleasant, unnatural/natural, and tinny/rich. Participants are also asked to compare rate three timbre dimensions using scales of: empty-full; dull-sharp; and smooth-rough. A test battery such as this, along with tests of perceptual accuracy, could be used in future studies to compare the GA MAP to a traditionally obtained MAP, given that perceptual accuracy and appreciation are two separate issues.

Future research into this area could also expand upon the current study by including a larger number of participants, and/or expanding the parameter space used for creating the GA MAP, meaning that there would be a greater number of potential MAPs that the GA could generate. Finally, such a study could also include a follow-up session to fine-tune the GA MAP after participants have had a chance to 'try it out'.

Although a MAP specifically for music listening may help to improve music perception accuracy and/or appreciation, research has indicated that focused listening practice is required for recipients to fully maximise their potential with their device (Galvin et al., 2007; Gfeller, Witt et al., 2000). Hence, a music training program could help maximise a participant's potential for music listening, regardless of which strategy or MAP they use. There is evidence from Participant 7 to support this. P7 had undertaken a great deal of focused music listening practice post-implantation, and this was reflected in his high MTB scores when compared to the other participants. Furthermore, P7 reported the highest number of comparisons of the two MAPs for music in their listening diary which suggests that they used the GA MAP more often. The focused practice along with the greater use of the GA MAP may have improved his perceptual sensitivity to the differences between the MAPs and/or enable him to better perceive the cues required for accurate music perception.

One further application of the GA software is for recipients using bimodal stimulation. Sucher & McDermott (2009) demonstrated the benefit of using a HA alongside a CI for music perception in nine post-lingually deafened adult Nucleus CI24 recipients. They found a significant benefit of using bimodal stimulation over a CI alone for tasks of familiar melody identification and complex sound identification ($p<0.05$). However, using a HA alongside a CI presents an additional challenge to clinicians who need to balance the sound perceived through each device. At present this is a two-step process (Ching, 2003). The first step involves participants listening to continuous speech whilst listening through their HA which has been programmed with two frequency responses, and then deciding which is better for understanding the speech. The second part involves the participant comparing the loudness of the signal coming through the HA with that coming through the CI, and the clinician adjusting the gain of the HA so that the loudness is perceptually similar (Ching, 2003). Both parts of the process involve adjusting the HAs to better match the CI. Given the evidence from this study that a GA can be efficiently used to create a MAP for specific listening situations, research could investigate the possibility of using the GA software to fine-tune the CI MAP for use in conjunction with a HA to allow for a more equitable balancing of the two devices.

4-4. Summary and Conclusions

This study found that a GA could be used in a clinically suitable manner to create a MAP for music listening. The results showed that the average time taken to create a MAP using the GA software was 35 minutes (range: 13-72 minutes) which is clinically appropriate when compared to current MAPping procedures. The results also showed that two participants created a MAP which they deemed worth keeping at the conclusion of their participation in the study, with a third stating their GA MAP performed equivalent to their current MAP.

Participants rated their GA MAP as slightly better for situations where music listening was the primary purpose, and as more natural, pleasant and better when at the cinema. Testing of participants on tasks of timbre identification, melody identification, and pitch ranking revealed that participants performed significantly better on the melody identification task with their GA MAP, and higher on the quarter-octave pitch ranking task with their original MAP. There were no other significant differences on these tasks found between the two MAPs. Participants scored an average of 89% for speech in quiet with their GA MAP, implying that speech perception skills would not be substantially disadvantaged if they were to use this GA music MAP for perceiving speech.

The results of the timbre identification tasks revealed that the participants performed significantly better on the single-instrument identification task than the ensemble identification task. This result was consistent with other studies (Looi et al., 2008; Looi & She, 2010) which also found that CI users are significantly more accurate on tasks that involve simple stimuli (e.g. one instrument) than tasks that involve complex stimuli (e.g. ensembles).

All participants displayed a positive attitude towards the GA fitting process, with four participants preferring it to a traditional MAPping procedure. Participants reported enjoying the freedom to work at their own pace and the feeling that they were in control of their own program. While participants were split as to whether they felt clinical supervision was necessary during the session, all but one participant stated that they would like this software available outside of the clinic, indicating that CI recipients are open to taking control of their own MAPs and to different approaches to creating a MAP.

In general, the participants in this study were not significantly disadvantaged when using their GA MAP for tasks of music or speech perception. They also tended to rate their GA MAP as slightly better for music listening. Although there were no other significant perceptual benefits of the GA MAP compared to their everyday MAP in this study, two participants felt that their GA MAP was of significant benefit to keep at the conclusion of the study. The results have also highlighted a host of other potential clinical applications of the GA programming software as well as areas that audiologists may need to address in counselling potential or new recipients. Given that the process of creating a GA MAP was not significantly more time-consuming than current MAPping sessions, the study has highlighted the potential for this approach to MAPping to be used in clinics to supplement traditional MAPping procedures.

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APPENDIX A: MUSIC TRAINING AND BACKGROUND QUESTIONNAIRE

Subject Information

Name .... Date ....
Date of Birth .... Age ....

Cochlear Implant Information

Ear Implanted ....
Do you use a different program or setting for listening to music Yes No
If yes, please specify (if known): ....
Date or Implant ....
Duration of bilateral, severe to profound hearing loss before implant operation (years) ....
Do you wear a hearing aid in the other ear? Yes No
If yes, type of aid: ....

Pre-Hearing Loss – Musical Listening Information	*Please circle one*

Prior to your hearing loss, how often did you choose to listen to music (e.g. Radio, tape, CD, concerts etc)?
Very Often Often Sometimes Occasionally Never

Since you received your CI, how often do you choose to listen to music?
Very Often Often Sometimes Occasionally Never
Approximately .... hours per week

Please indicate which statement below best describes how your enjoyment of music has changed from prior to your hearing loss to the present day (with your CI).

- ☐ I never really listened to music before my hearing loss, and I do not listen to it now
- ☐ Music is not as pleasant as I recall before my hearing loss, but it is better than nothing
- ☐ Music is not as pleasant as I recall before my hearing loss, but I still enjoy it now.
- ☐ Music sounds different to what I recall, but is no less enjoyable
- ☐ Music does not sound any different to what I recall before my hearing loss
- ☐ Music is more pleasant sound than I recall before my hearing loss

Please indicate which statement below best describes how your music listening habits have changed from pre-hearing loss to the present day (with your CI)

- ☐ No change – I did not listen to music before my hearing loss, and do not do so now
- ☐ No change – I listened to music occasionally before my hearing loss, and listen to it occasionally now
- ☐ No change – I listened to music frequently before my hearing loss, and listen to it frequently now
- ☐ I listened to music more before my hearing loss than now
- ☐ I listen to music more now than before my hearing loss.

Musical Training Information

The following questions refer from the time prior to your hearing loss through to the present day

Have you ever had instrumental (or practical) music lessons (i.e. specifically for a music instrument or voice/singing)

Yes No

If yes, lessons	Instrument	Number of years of lessons	Age received
	______________	______________________	_________________
	______________	______________________	_________________
	______________	______________________	_________________

Did you complete formal music exams in the above instrument(s) or voice?

Yes No

If yes,	Instrument	Grade level achieved
	______________	______________________
	______________	______________________
	______________	______________________

Did you ever do music, as a subject, at school, university, polytechnic, TAFE, adult colleges or any other post-school learning institution(s)?

Yes No

If yes,	Place	Number of Years	Age involved in class(es)
Primary School	______________	______________________	_________________
High School	______________	______________________	_________________
University	______________	______________________	_________________
Polytechnic	______________	______________________	_________________

TAFE	______	______	______
Adult College	______	______	______
Other (specify)	______	______	______

Have you ever been involved in a music group or ensemble (e.g. Band, choir, orchestra etc)?

Yes No

If yes,	Group	Number of Years	Age involved
	______	______	______
	______	______	______
	______	______	______

Have you ever participated in music appreciation, music theory or music history classes (e.g. learning about composers, styles, harmony, composition, keys etc)?

Yes No

If yes,	Type of Class involved	Number of Years	Age
	______	______	______
	______	______	______
	______	______	______

Have you ever been involved in any other formal music classes, experiences, activities etc not covered above?

Yes No

If yes,	Type	Number of Years	Age involved
	______	______	______
	______	______	______
	______	______	______

Please detail any informal music classes, activities, experiences etc. that you have been involved in (e.g. 'self-taught' musician, learning an instrument 'by ear' or with friends, own 'music training program', personal research for self interest and information etc).

Please include detail regarding number of years and age at which the activity(s) was undertaken.

______
______
______
______
______
______

On a scale of 1-5, please rate the following:

(1 = None or not able; 2 = Limited; 3 = Average; 4 = Above Average; 5 = Extensive or Very Able)

Knowledge of music history

1 2 3 4 5

Knowledge of music theory

1 2 3 4 5

Ability to read music

1 2 3 4 5

Ability to play an instrument or sing

1 2 3 4 5

Overall music ability

1 2 3 4 5

Comments

The following questions refer to the time period since you received your cochlear implant.

Since you received your implant, have you:

Ever had formal instrumental (or vocal) music lessons?

Yes No

If yes, please detail

Ever attended music appreciation, music history, or music theory lessons?

Yes No

If yes, please detail

Ever participated in music group or ensemble (e.g. Choir, band, orchestra etc)?

Yes No

If yes, please detail

Ever taught yourself a music instrument, singing or music theory?

Yes No

If yes, please detail

Ever tried to improve your music perception ability?

Yes No

If yes, please detail

____

Do you have any other additional information or comments?

____

APPENDIX B: GENETIC ALGORITHM FITTING QUESTIONNAIRE

Subject ID: ______________________ Date: ______________________

We would like to know how you felt about the fitting approach used in this study.

Thank-you for taking the time to fill out this questionnaire

	YES	Ambivalent*	NO
1. Were you excited about creating a custom music program?	O	O	O
2. Was the procedure fun/enjoyable?	O	O	O
3. Did you prefer it to a traditional procedure?	O	O	O
4. Did you like the freedom to work at your own pace?	O	O	O
5. Did you like being in control of creating your own program?	O	O	O
6. Should clinics offer an approach like this?	O	O	O
7. If so, would you be more motivated to visit your clinic?	O	O	O
8. Would you use software like this on your home computer?	O	O	O
9. What about on a hand-held device (egg. remote control)?	O	O	O
10. Would you feel confident customizing your program without clinical supervision?	O	O	O
11. Would you like to use it to customize programs for other listening situations (television, restaurants, movies, church, etc.)?	O	O	O
12. Do you have concerns about a customization session taking too long?	O	O	O

*Please note: Ambivalent in this case means that you had no strong opinion either way.

- Please, turn over -

What did you like about this approach to MAPping?

What did you not like about this approach to MAPping?

How would you improve it?

Appendix C: Listening Diary Sample Page

Date: _______________ Amount of time spent in this situation: _____hr, ____mins

Location (e.g. home, work, church, shops, car, party etc.): _______________________________________

Describe the Listening Situation (e.g. number of people present, number of people conversing with, presence/absence of background noise, radio, TV, etc.):

____
____

Comments:

____
____
____

The scales below are to compare Program 1 vs. 2 for this situation. *(Please place a X on the line, according to your opinion, for each of the 3 scales below).*

For this situation:

Prog. 1 much more	No difference between Prog. 1 & 2	Prog. 2 much more

Prog. 1 much more natural	No difference between Prog. 1 & 2	Prog. 2 much more natural

Prog. 1 much better for this situation	No difference between Prog. 1 & 2	Prog. 2 much better for this situation

Why:

____
____
____