The Development and Pilot Testing of a Music Quality Rating Test Battery for New Zealand and Australian MED-EL Cochlear Implant Recipients

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A thesis submitted in partial fulfilment of the requirements for the

Degree of Master of Audiology

in the University of Canterbury

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University of Canterbury

2010

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LIST OF ABBREVIATIONS

ACE	Advanced Combination Encoder
BM	Basilar membrane
CD	Compact disc
CI	Cochlear implant
CIS	Continuous Interleaved Sampling
CNC	Consonant-Nucleus-Consonant
CSSS	Channel Specific Sampling Sequences
CUNY	City University of New York
EAS	Electro-acoustic stimulation
F0	Formant frequency
FS	Fine structure
FSP	Fine Structure Processing
HA	Hearing aid
HDCIS	High Definition Continuous Interleaved Sampling
HiRes	High Resolution
IFT	Impedance and field telemetry
JND	Just noticeable difference
MPS	Mid-point scale(s)
MQRTB	Music Quality Test Rating Battery
NH	Normal hearing
NZ	New Zealand
pps	Pulses per second
QOL	Quality of life
SNR	Signal-to-noise ratio
SSD	Session Strategy Difference
WL	Waiting list
VAS	Visual-analogue scale(s)

ACKNOWLEDGEMENTS

Thank you firstly to Dr Valerie Looi, for suggesting this topic, and providing such valuable guidance throughout the process. To MED-EL GmbH, thank you for funding this research, and thank you especially to Gregor Dittrich and Dr Ilona Anderson for their support, advice, and assistance. Thank you also to Dr Gregory O'Beirne for writing the touchscreen program which became such an integral part of the data collection process.

Thank you to the staff at the Southern Cochlear Implant Programme (Christchurch), and the Lions Hearing Clinic (Perth) for their support, facilities, and for allowing their patients to be part of the study. Especially, thank you to Catherine Sucher, Leonard Healy, Beth Kempen, and Penny Monteath. Also, thank you to Dr Emily Lin and Peter Smith for their statistical analysis advice, Dr Peter Nopp and Andreas Krenmayr for clarifying some of the technical aspects of FSP, and Uta Heidtke for her help with phase one of the MQRTB development.

To my wonderful wife Amanda, and Roselle, Luke, and Tobias, thank you for supporting me in this adventure, never complaining about the demands this research has made of my time, and reminding me that life is for living. I promise that 'Daddy's busy' will be a much-less-heard phrase from now on.

And finally, a big thank you to all of the participants of the various stages of this research, but especially to the five participants who took part in the FSP versus HDCIS study. It has been an honour getting to know you, listening to your stories, and sharing in the joy that cochlear implants have brought to your life. You have taught me to never take the ability to hear for granted.

ABSTRACT

Many cochlear implant (CI) recipients report the sound quality of their devices to be poor, for listening to music. The latest MED-EL speech processing strategy, Fine Structure Processing (FSP), aims to improve sound quality by encoding some of the low-frequency fine structure (FS) information.

The goals of this study were twofold. The first was to develop a music quality rating test battery (MQRTB) for the New Zealand and Australian populations using commercially available songs. The second was to pilot test the MQRTB in a study comparing the MED-EL speech processing strategies FSP and High Definition Continuous Interleaved Sampling (HDCIS) for music appreciation. The research questions for the second part of this study were: (1) Does familiarity with a speech processing strategy affect musical quality ratings?; (2) Do CI recipients notice a significant difference between FSP and HDCIS when listening to music and if so, what aspects of the sound are different?; (3) Does song familiarity affect the quality ratings of music in CI recipients?; (4) Does music genre affect the quality ratings of music in CI recipients?

The MQRTB used visual analogue scales for the attributes of pleasantness, naturalness, richness, fullness, sharpness, and roughness while listening to a home stereo. The scales were displayed on a computer touchscreen with the stimuli being presented via a home stereo system. There were ten songs in the MQRTB; a familiar and obscure song from each of the following genres: classical, modern, country and western, and common (such as a national anthem or iconic melody) genres, as well as two of the participant's favourite songs.

Five post-lingually deafened MED-EL Sonata$_{\text{TI}}^{100}$ or Pulsar$_{\text{CI}}^{100}$ CI recipients using the FSP strategy took part in the FSP versus HDCIS comparison study. Each participant spent three weeks acclimatising to either FSP or HDCIS before completing speech perception testing and the MQRTB task. Following this the participants were switched to the other speech processing strategy to acclimatise to for a further three weeks before re-assessment with the second strategy. At the conclusion of the study, the participants' speech processors were returned to the pre-study settings.

The results of the study showed an effect of acclimatisation on music quality ratings; when the participants were acclimatised to FSP, the group tended to prefer FSP; however, when acclimatised to HDCIS, the participants did not prefer HDCIS. As a group they rated FSP to sound closer to 'what they would like music to sound like' than HDCIS, and that HDCIS sounded significantly sharper and rougher than FSP. This suggested that music appreciation was better with FSP, but participants needed to be acclimatised to the strategy first. No effect of familiarity or genre was observed in the averaged group data, however, effects for some individuals were noted.

Overall it would appear that FSP may improve music sound quality for some MED-EL CI recipients, however, it does not solve this issue. The MQRTB was also shown to be an effective tool to assess some aspects of music sound quality.

Chapter 1. Overview

The role of music in society is pervasive from birth to death, being used to entertain, relax, advertise, evoke emotional responses, mark significant life events, and link individuals to their culture (Hays & Minichiello, 2005; Tramo, 2001). Music perception and enjoyment in cochlear implant (CI) recipients, however, is typically poor (Looi, 2008). This study aims firstly, to develop a music quality rating test battery (MQRTB) and secondly, to investigate how CI recipients rate music to sound using a relatively new speech processing strategy.

The introductory part of this thesis consists of three chapters. Chapter 2 provides an overview of sound, hearing, CIs and music as relevant to this study. Section 2.1 describes the nature of acoustic stimuli and how pitch is encoded in normal hearing, and Section 2.2 is an explanation of the purpose and function of CIs, the details of the devices and speech processing strategies relevant to this study, how pitch and timbre are encoded in CIs and how music quality is related to quality of life for CI recipients.

Chapter 3 reviews current CI literature, focusing on studies involved with the perception of various musical attributes. This leads to Chapter 4 which discusses the rationale behind the current study, and the aims and hypotheses of this research.

Incorporated into Chapter 5 are the methods (Section 5.1) and results (Section 5.2) for the MQRTB development. This was done to ensure that the reader has a full understanding of the MQRTB development prior to reading the methods for the second aim of the study, the comparison of speech processing strategies. Chapter 6 contains the methods (Section 6.1) and results (Section 6.2) for the study comparing music quality ratings for CI recipients with two different speech processing strategies. Chapter 7 contains a discussion of the findings, clinical implications, limitations of the study, and suggested future research.

Chapter 2. Acoustic Signals, Theories of Pitch Perception, and Cochlear Implants

2.1 Complex Acoustic Signals

The mathematician David Hilbert demonstrated that complex sounds can be decomposed into a slowly varying envelope and a high-frequency carrier called the fine structure (FS) (Hilbert, 1912) (Figure 2.1). The envelope is defined as the relatively slow variations in amplitude over time, whereas the FS is the rapid oscillations that occur at a rate close to the centre frequency of the band (Moore, 2008). In other words, the envelope shows how the amplitude of the original waveform changes over time and gives information on the spectral shape, whereas the FS is the frequency specific information contained within the original waveform which carries information about both the fundamental frequency (F0) of the sound, and additional harmonics which combine to form its short term spectrum.

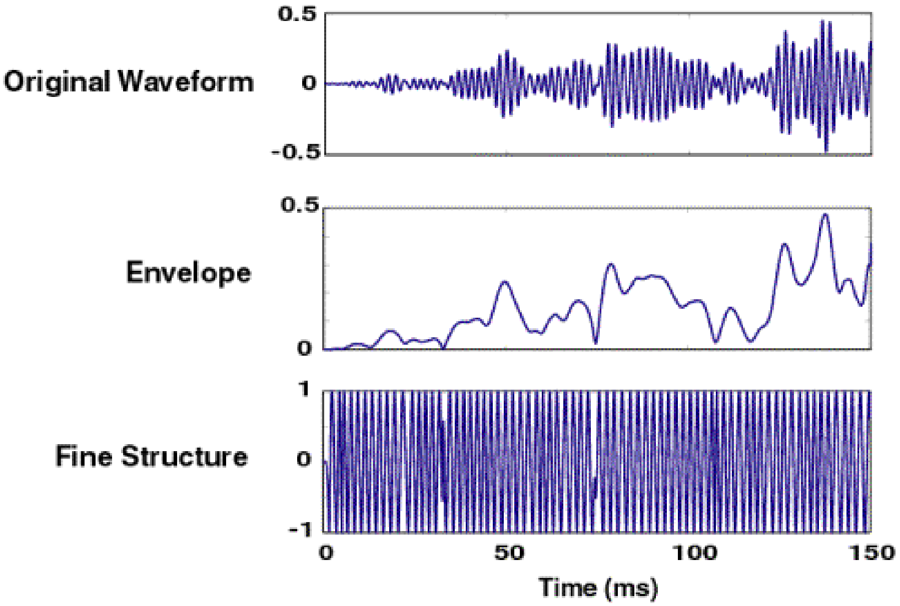

Figure 2.1: **An example of an acoustic signal decomposed using a Hilbert transform into the fine structure and envelope. As shown in (Wilson, et al., 2005)**

The example of an acoustic signal being decomposed into its envelope and FS shown in Figure 2.1, illustrates that each contains separate, yet complimentary information required to encode the original signal. By using auditory chimeras, which combined the envelope of one speech or melody sample with the FS of another, Smith, Delgutte, and Oxenham (2002) found that the envelope was most important for speech understanding, whereas the FS was most important for music perception and sound localisation. They also found that when there was conflicting envelope and FS information the perceived content was determined by the envelope, but the location by the FS. It was suggested that the FS may prove to be important for separating the talker and background noise into separate auditory streams (Friesen, Shannon, Baskent, & Wang, 2001; Moore, 2008), and provide better representation of frequency information in either speech or music (Smith, et al., 2002).

2.1.1 Music Attributes

Music, like speech, is an acoustic stimulus with a set of rules for combining a limited number of sounds in a multitude of ways (Lerdahl & Jackendorff, 1983; Limb, 2006); however, music and speech differ in their functions in society (Gfeller, Knutson, Woodworth, Witt, & DeBus, 1998; Vongpaisal, Trehub, & Schellenberg, 2006), and in how they are perceived, encoded and interpreted (Shannon, 2005). In particular, as mentioned previously, speech recognition in quiet depends on the envelope information, whereas music listening requires the FS information in the signal as well (Smith et al., 2002).

Speech understanding is a top-down pattern recognition task that is learned from experience, and is possible with highly distorted and degraded signals for many normal hearing (NH) listeners, as the brain relies on context-dependent pattern recognition to identify words (Shannon, 2005; Shannon, Qian-Jie, Galvin, & Friesen, 2004). The addition of visual cues, and the ability to confirm perceptual accuracy through questioning also assist with comprehending speech in challenging situations to a greater extent than for music listening.

Music can be deconstructed into the major elements of rhythm, pitch and timbre, regardless of genre or style. Rhythm is the temporal aspect of musical sounds which typically occurs in the frequency range from 0.2 to 20 Hz (McDermott, 2004) and is considered to be the most basic feature of music (Limb, 2006).

Pitch is defined by the American Standards Society (1960) as "that attribute of auditory sensation in terms of which sounds may be ordered on a musical scale" (Moore, 2003, p. 3). Pitch is the psychoacoustic correlate to the repetition rate of the waveform of a sound; for a puretone this corresponds to the frequency, and for a complex tone, which is two or more different puretones presented at once, usually its F0 (Milczynski, Wouters, & van Wieringen, 2009; Moore, 2003). Although pitch is primarily determined by frequency, sound level can also play a small role for individuals, where the pitch of tones below about 2000 Hz tends to decrease with increasing level, while the pitch of tones above 4000 Hz increases with increasing level (Moore, 2003). The sequential presentation of pitches in an organised manner constitutes melody, whereas simultaneous presentation of pitches in an organised manner constitutes harmony. The perception of both melody and harmony relates directly to the ability to correctly perceive relative pitches.

Timbre is the quality of sound independent of pitch and loudness, defined by the American Standards Association as "that attribute of auditory sensation in terms of which a listener can judge two sounds similarly presented and having the same loudness and pitch are dissimilar" (in von Bismark, 1974b, p. 147). This allows the listener to distinguish between various instruments playing the same note or melody at the same loudness, and contributes significantly to the quality of the listening experience. The description of timbre is challenging, however, as it is a multi-dimensional concept. For example von Bismark (1974b) found that 88% of the variance in timbre can be accounted for by the three rating scales of dull-sharp, compact-scattered, and full-empty. He reported that NH listeners judged sounds with more low-frequency energy as more dull, and sounds with more high-frequency energy as more sharp on the dull-sharp continuum, sounds with more noise as sounding more scattered on the scattered-compact continuum, and sounds with more harmonics as more full on the full-empty continuum.

Successful melody perception relies on the accurate perception of relative, rather than absolute pitch distances between two successive tones (Peretz & Zatorre, 2005); for western music the perception of pitch distances down to one semitone is required. Some care needs to be taken, however, as although these aspects (i.e. rhythm, pitch, and timbre) are useful to describe, analyse, and measure music perception, the typical listener tends to consider music as an organic whole rather than a collection of parts (Limb, 2006; Smith, Nelson, Grohskopf, & Appleton, 1994). Music enjoyment is very complex and cannot be addressed solely as a function of perceptual accuracy, but as an interaction between a range of variables which collectively contribute to music appreciation and enjoyment (Lassaletta, et al., 2008b; 2007).

2.1.2 Pitch Coding in Normal Hearing

Pitch perception is very complex and not yet fully understood. The two sections below provide a very simplistic and basic overview; for a more comprehensive description of pitch perception see Plack, Oxenham, Fay, and Popper (2005) and Moore (2003).

Pitch Perception in Normal Hearing for Puretones

Pitch perception of puretones in NH individuals has traditionally been explained with three separate, yet co-existing, theories: the place theory, the temporal theory and the place-temporal theory.

The place theory of pitch perception is based on the spatially arranged frequency regions along the length of the cochlea transitioning from base to apex. This is referred to as tonotopicity. When a tone is presented to the auditory system, the cochlea carries out a mechanical form of a Fourier transform to map the frequency to a specific region on the basilar membrane (BM), hence stimulating region-specific, and therefore frequency-specific neurons (as shown in Figure 2.2). Tonotopic representation continues up the auditory pathway to the auditory cortex, with stimulation patterns being utilised to deduce which region of the BM is vibrating.

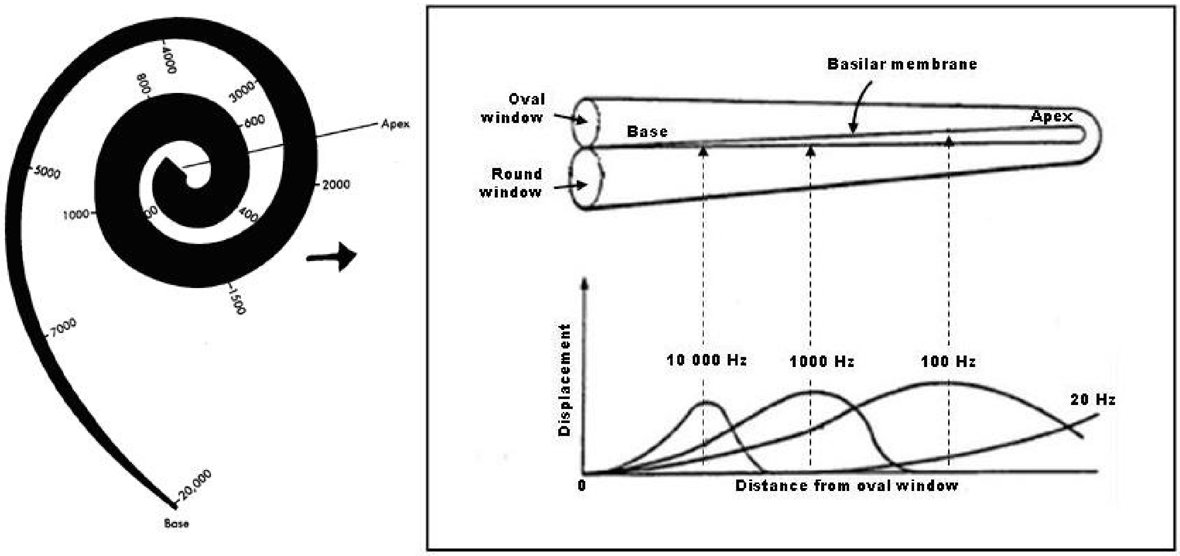

Figure 2.2: **Illustrations of the tonotopic arrangement of the cochlea (left), and a representation of the linear length of the cochlea with frequency positions indicated (right) (Cullen, n.d.)**

The temporal theory suggests that the pitch of a stimulus is related to the time pattern of the neural impulses evoked by that stimulus. That is, the neural firing pattern matches the phase and waveform of the stimulus. This phenomenon is referred to as phase-locking, and results in firing patterns showing an inter-spike latency equivalent to a multiple of the period of the sinusoid (see Figure 2.3). Phase-locking in NH has been found to be efficient at low frequencies up to around 2000 Hz, at which point the degree of synchronicity declines until it is nearly non-existent around 5000 Hz (Drennan & Rubinstein, 2008).

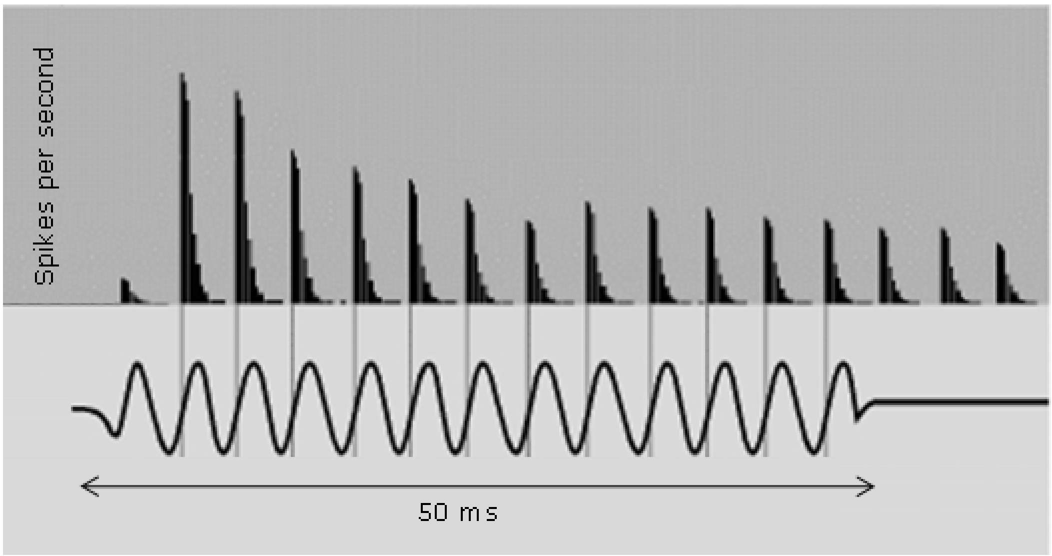

Figure 2.3: Temporal response patterns of a low-frequency axon in the auditory nerve showing phase locking to a stimulus.
The stimulus waveform is indicated beneath the histograms, which shows the phase-locked responses to a 50-ms tone pulse of 260 Hz. Note that the spikes are all timed to the same phase of the sinusoidal stimulus (Fitzpatrick, 2007).

Lastly, the place-temporal theory suggests the pattern of excitation along the BM may also provide information on the component frequencies. When a travelling wave moves down the BM, phase differences exist between the peaks and troughs of the sinusoid. The rate of change of these phase differences, and the relative positions of the peaks and troughs at a particular time depend on the frequency of the stimulating sound, which can be used to deduce pitch (Loeb, White, & Merzenich, 1983; Oxenham, 2008).

Pitch Perception in Normal Hearing of Complex Tones

The place theory of pitch perception has some difficulty in explaining how complex tones, which consist of two or more different frequencies presented at once, are perceived. There are situations where the perceived pitch does not correspond to the position of maximum excitation. For example, two complex tones which are identical except that one has the F0 removed, will elicit the same pitch but have slightly different timbres (Moore, 2003). It therefore appears that harmonics, which are integer multiples of the F0, contribute significantly to the pitch percept, and that there is more to pitch perception than pure place coding of the F0. (Geurts & Wouters, 2001).

Research indicates that the pitch of a complex sound can be derived either from the resolved lower harmonics (Houtsma & Goldstein, 1972), or from the higher unresolved harmonics (Houtsma & Smurzynski, 1990; Moore & Rosen, 1979). In a NH cochlea, the auditory filter bandwidths are narrower for low-frequency sounds and widen as the frequency increases. As a result, low-frequency harmonics fall within a single filter, and are resolved, producing individual peaks at frequency specific locations on the BM. The timing of the neural spikes derived from these resolved harmonics relate to the frequency of the individual harmonic rather than the F0. At higher frequencies the wider filter spacing results in a number of harmonics falling within one filter, and these superimpose to produce a combined waveform. This waveform shows an amplitude modulation equal to the F0, which is encoded in the timing of the neural spikes in this region. Therefore for these higher unresolved harmonics, the F0 is encoded by the neural firing patterns (Oxenham, 2008).

In summary, for complex sounds the key for pitch perception is the ability to extract the F0 information from the signal. This can be achieved by either resolving the individual frequency components present in the signal, and/or extracting the temporal information from the unresolved components; however, none of the three theories of pitch perception (place, temporal, and place-temporal) can fully account for all of the phenomena or anomalies associated with pitch perception.

2.2 Cochlear Implants

2.2.1 A Historical Perspective on the Development of Cochlear Implants

Cochlear implants, to date, are the most successful neural prosthesis for restoring partial hearing to severe-to-profoundly deaf people (Wilson, 2004). Originally, CIs only provided an awareness of environmental sounds and aided in speech reading (Wilson & Dorman, 2008; Zeng, 2004); however, technology has since advanced to a point where most recipients obtain good speech perception in quiet environments (Rubinstein & Hong, 2003). Historically, the focus of perceptual-related technological advances in the CI industry has been to improve speech perception (Tyler, Gfeller, & Mehr, 2000); however, as most current recipients achieve excellent speech discrimination in quiet, the interest has spread to the perception of other acoustic stimuli such as music. Wilson and Dorman (2008), Grayden (2006), and Zeng (2004) provide comprehensive summaries on the historical development of CIs.

2.2.2 Cochlear Implant Components and Functioning

A CI is a neural prosthesis comprising internal and external components. As shown in Figure 2.4, CIs have the following features in common: a microphone which detects the sound input, and transduces the input from an acoustic to an electric signal; a speech processor which converts electrical signals into patterns of electrical stimulation; a transcutaneous[1] transmission system consisting of an externally worn transmitter coil which relays the electrical signals to a magnetically connected subcutaneous receiver-stimulator which decodes the signal; and an electrode array (consisting of multiple electrodes) which is connected to the receiver-stimulator and is inserted into the cochlea (see Loizou, 1998). The implanted receiver-stimulator and electrode array are commonly referred to as the receiver-stimulator package.

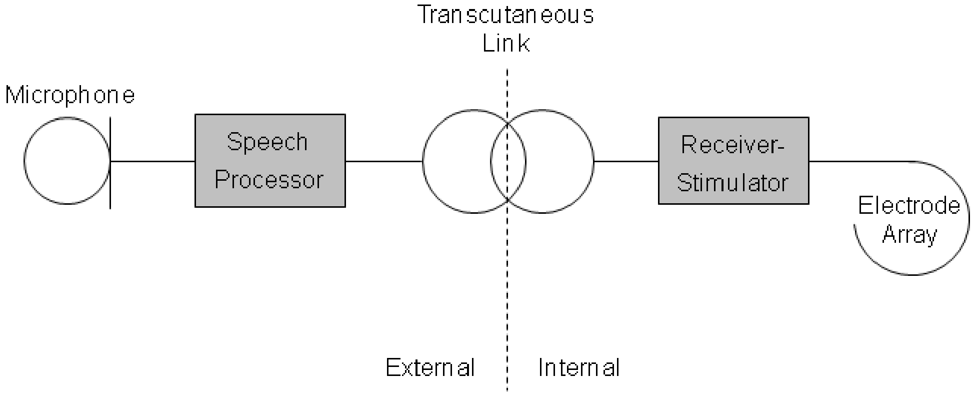

Figure 2.4: **The components of a CI with a transcutaneous transmission link. (Wilson, 2004). Adapted**

The electrode array is inserted into the scala tympani of the cochlea and delivers electrical currents which bypass damaged or missing hair cells, and stimulate the spiral ganglion cells inside the modiolus directly. This stimulation generates action potentials in the auditory nerve fibres which are transferred to the auditory cortex and percieved as sound (Grayden & Clark, 2006). The electrode arrays vary in style, length, and number of stimulating electrodes, depending on the manufacturer, but are typically 24.5 to 31mm long and contain 6 - 22 electrodes, which allow for site-specific electrical stimulation. Stimulation of individual electrodes allows for the tonotopic organisation of the cochlea to be exploited (see Figure 2.2), with basal

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[1] Transcutaneous refers to the transmission of information across the unbroken skin via magnetic induction.

stimulation leading to a higher pitch sensation than apical stimulation. This aims to replicate the frequency mapping in the normal cochlea (Wilson, 2006).

Within the external speech processor a speech processing strategy (discussed further in Section 2.2.4) is implemented, which converts electrical signals from the microphone into patterns of electrical stimulation, the parameters of which are programmed into the speech processor by the patient's audiologist. All manufacturers have different strategies and philosophies on how they process incoming sound, but currently there is little difference in performance outcomes on functional speech perception scores (Rubinstein, 2004; Wilson, 2006). All current clinical strategies employ a filterbank to separate the incoming sound into its frequency components, with the output of each filter in the filterbank being mapped onto an individual electrode in the array. Depending on the manufacturer, the number, width, and shape of these filters vary in order to comply with the number of electrodes on the array. The first time a speech processor is attached and turned on is referred to as 'switch on', at which point an audiologist adjusts parameters such as speech processing strategy and maximum and minimum levels of electrical stimulation on each individual programme. As the CI recipient's brain adjusts to the new input, this programming process requires continual revisiting and refining before stability is reached. The process of the brain becoming accustomed to programming changes is commonly referred to in the literature as acclimatisation, which is defined in the Oxford dictionary as "to make or become accustomed to a new climate or new conditions".

Currently there are three main manufacturers of CIs worldwide; MED-EL (Austria), Cochlear Limited (Australia), and Advanced Bionics (USA), who use FSP, ACE, and HiRes respectively, as their default speech processing strategies. This study is solely focused on MED-EL CIs using either the FSP or HDCIS strategies, which are described in the following sections.

2.2.3 Specifics of the MED-EL MAESTRO® Cochlear Implant System

The MED-EL MAESTRO® system offers two CI devices, the Pulsar$_{CI}^{100}$ which has a ceramic casing and the Sonata$_{TI}^{100}$ which has a titanium casing (Figure 2.5). The maximum total rate of stimulation for either implant is 50,704 pulses per second (pps). Both implants use an extracochlear electrode for the return current path placed on the casing of the receiver-stimulator package for the Sonata$_{TI}^{100}$, and as a ball electrode positioned under the temporalis muscle for the Pulsar$_{CI}^{100}$ (Ramsden, 2006). Several electrode arrays are available, however, the 31mm long standard array contains 24 platinum electrodes, arranged as 12 pairs, 2.4mm apart. This covers a cochlear range of 26.4mm, which, assuming full insertion, is around the place corresponding to 800 Hz in the cochlea (Nobbe, Schleich, Zierhofer, & Nopp, 2007).

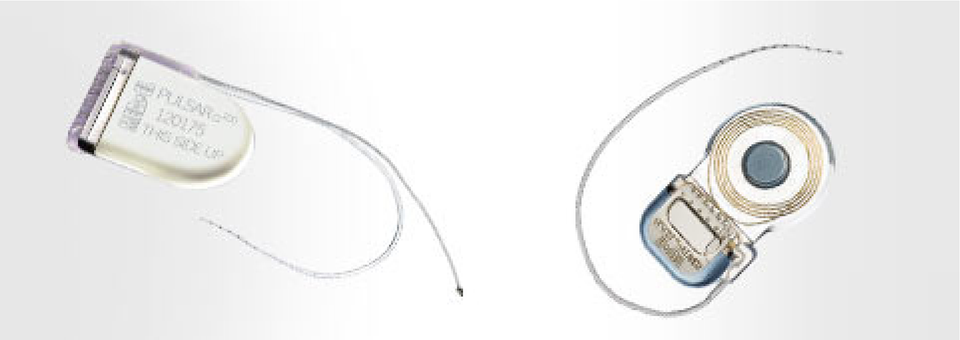

Figure 2.5: **The PULSAR$_{CI}^{100}$ and SONATA$_{TI}^{100}$ cochlear implants (MED-EL GmbH, 2009). Note the ball electrode clearly visible on the PULSAR$_{CI}^{100}$ (left).**

The current speech processor is the Opus 2, which is an ear level device controlled by the FineTuner remote (Figure 2.6). This processor is backwards compatible with the previous Combi 40+ MED-EL CI, and has numerous wearing options, an integrated telecoil, and an audio input jack for utilising devices such as MP3 players, wireless FM, and Bluetooth® systems.

Figure 2.6: **An Opus 2 speech processor with attached transmitter coil and accompanying FineTuner remote control. (MED-EL GmbH, 2009).**

2.2.4 Speech Processing Strategies

Most currently used clinical speech processing strategies such as Continuous Interleaved Sampling (CIS), Advanced Combination Encoder (ACE), and High Resolution (HiRes) use biphasic pulses sequentially presented at high fixed rates to stimulate the cochlea (Vandali, Whitford, Plant, & Clark, 2000; Wilson, 2006; Wilson, Finley, Lawson, Wolford, & Zerbi, 1993). Biphasic pulses, which consist of a first phase of one polarity followed by a second phase of opposite polarity, are used because they are charge balanced, leading to no net movement of charge, and are therefore safe to use with human patients (van Wieringen, Macherey, Carlyon, Deeks, & Wouters, 2008). Figure 2.7 gives an example comparing sequential to simultaneous biphasic pulses. Sequential pulses are used in current speech processing strategies as simultaneous stimulation leads to the summing of current from adjacent electrodes, and therefore a degradation of channel independence (Wilson, et al., 1993). High rates should theoretically allow for a more detailed representation of temporal information by encoding finer amplitude variations, and possibly neural firing patterns that more closely approximate those from acoustic stimulation (Grayden & Clark, 2006; Vandali, et al., 2000).

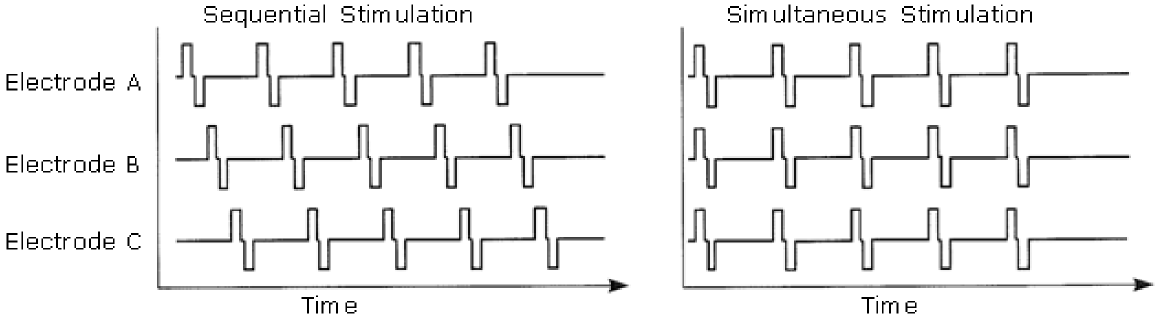

Figure 2.7: An expanded display comparing sequentially and simultaneously presented biphasic pulses.
For sequential stimulation, the pulses are presented in a non-overlapping manner whereas for simultaneous stimulation, the pulses are presented to the electrodes at the same time (Looi, 2008).

The initial stage of signal processing, which is common to all current processing strategies, involves passing the microphone output through a pre-emphasis filter to attenuate the louder low-frequency components in speech that may otherwise mask important high-frequency components. This is then passed through a filterbank which separates the signal into frequency bands or channels. All current commercially available strategies, with the exception of MED-EL's FSP strategy then extract only the envelope information and discard the FS (Arnoldner, et al., 2007). Research shows that only four spectral channels of envelope information presented in the correct tonotopic place are required for adequate speech recognition in quiet (Shannon, 2005; Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995); FS information does not appear to be necessary for speech recognition in quiet (Shannon, et al., 1995).

Processing strategies differ in many other aspects, including the type of compression used to map the wide dynamic range of sound into the narrow dynamic range of electrically evoked hearing, the method of sampling the waveform (e.g. Hilbert transform, half wave, or full wave rectification), and whether particular aspects of the sound are selected for stimulation (Wilson, 2006). For example, the ACE strategy uses a ‘peak picking’ method to select and encode only the most prominent spectral features of an input signal, thereby stimulating a subset of the total number of available electrodes. In comparison the CIS strategy stimulates all electrodes on the array regardless of the spectral characteristics of the input. A comprehensive review of these and older strategies is provided by Wilson (2004, 2006), and Loizou (1998).

Continuous Interleaved Sampling

The original CIS strategy as outlined by Wilson et al. (1991) used high sequential stimulation rates, usually exceeding 800 pps per channel. Several manufacturers have since adapted the original 1991 strategy to suit the individual features of newer implant systems. As shown in Figure 2.8, once the initial pre-emphasis and filterbank processing is completed, the output in each channel of the bandpass filter is rectified and lowpass filtered to extract the envelope of the signal. This is followed by compression via a non-linear transformation such logarithmic or power-law to fit the output into the typically limited dynamic range of a CI recipient (Wilson, 2004). The resulting envelope information is finally used to modulate biphasic carrier pulses, therefore the amplitude of these pulses reflect the amplitude of the envelope (Wilson, et al., 1991).

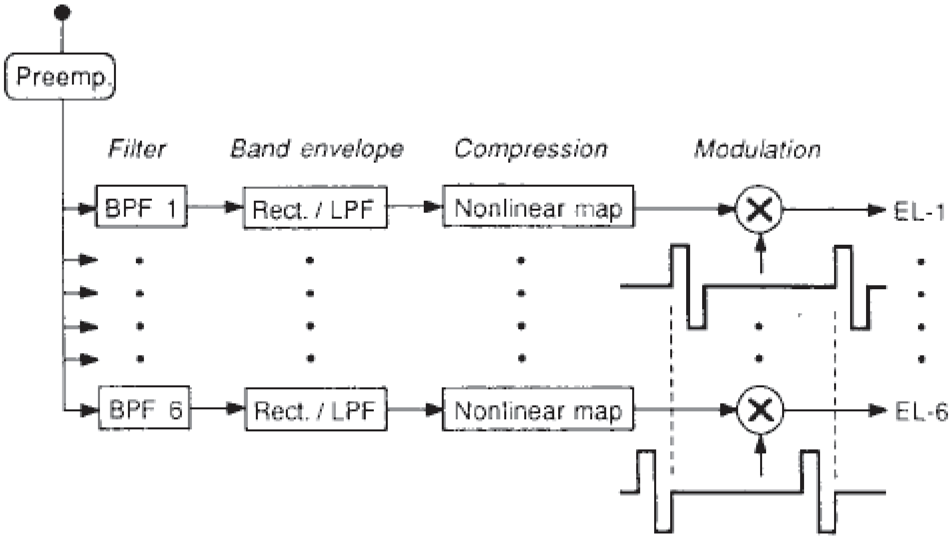

Figure 2.8: A block diagram of the CIS strategy.
Pre-emphasis (Preemp) is followed by a filterbank of bandpass filters (BPF). Each BPF output is rectified and lowpass filtered (Rect./LPF), with the resulting envelope undergoing compression (nonlinear map) before being used to modulate biphasic pulses. The resulting output from each BPF is used to stimulate separate electrodes in the array (EL1 – 6) (Wilson, et al., 1991).

An example of the output of CIS is shown in Figure 2.9 in response to an input of the phonemes /ɔ/ ('aw') and /t/ ('t'). This diagram shows that the FS of the signal is discarded, and the amplitude of the pulses reflect the envelope's amplitude. It also shows the input signal is broken down into its component frequency bands, and used to stimulate the tonotopically arranged electrodes, with the low-frequency dominant /ɔ/ encoded mainly in the apical channels (1,2), whereas the high-frequency dominant /t/ is represented predominately in the basal channel (4).

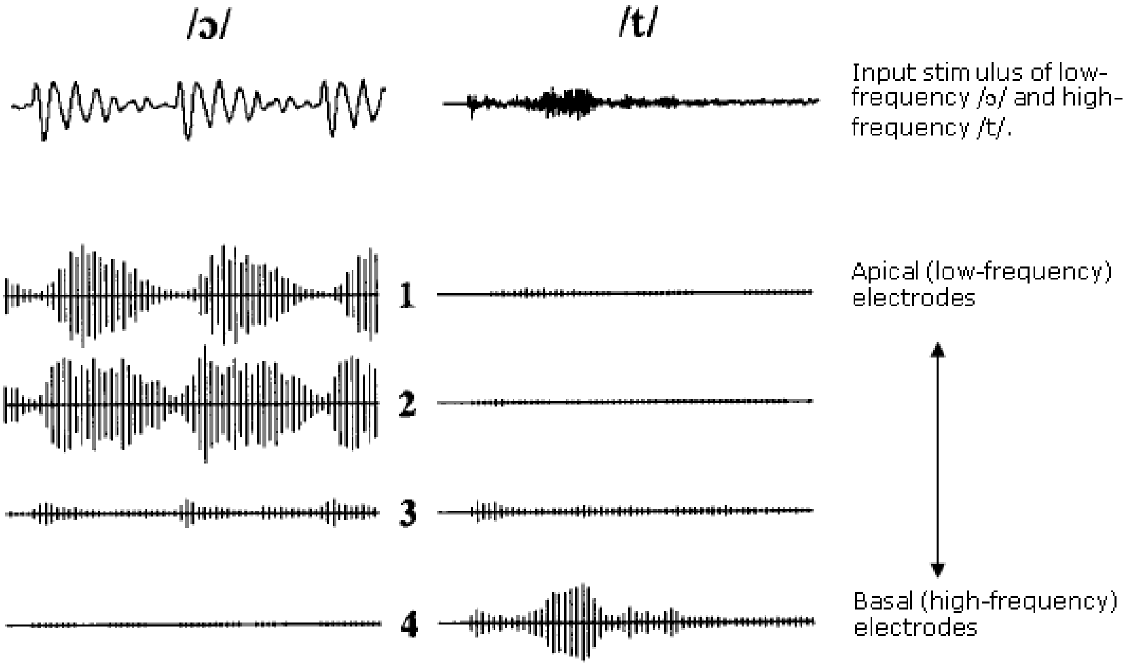

Figure 2.9: A simplified diagram of a four channel CIS filterbank strategy
Shown is the input waveforms of the low-frequency voiced phoneme /ɔ/ ('aw') and high-frequency unvoiced phoneme /t/ ('t'), and how these are encoded in a simplified 4 channel CIS strategy. The low-frequency dominant /ɔ/ is encoded mainly in the apical channels (1,2), whereas the high-frequency dominant /t/ is represented predominately in the basal channel (4). This therefore mirrors the tonotopic arrangement of the cochlea. (Wilson, et al., 1991). Adapted.

Further development of CIS has led to CIS+ which has an extended frequency range compared to CIS, and uses a Hilbert transform as opposed to the original full wave rectification to allow a more accurate determination of the signal envelope and FS (Helms, et al., 2001; Nie, Barco, & Zeng, 2006). Further development of CIS+ has led to High Definition CIS (HDCIS), which is currently available in the MED-EL MAESTRO® CI system. This differs from CIS+ by allowing a higher stimulation rate per channel, and expands the analysis frequency range down to 70 Hz compared to 250 Hz for CIS+ (Arnoldner, et al., 2007). CIS+ was the default switch-on strategy with the MED-EL TEMPO+® system from 1999 until the introduction of the MAESTRO® system in 2007.

Fine Structure Processing

Fine Structure Processing is the current default strategy for MED-EL CI recipients. It can currently be implemented with the Pulsar$_{\text{CI}}^{100}$ and Sonata$_{\text{TI}}^{100}$ CIs when used in conjunction with the Opus 2 speech processor (see 2.2.3). As mentioned, all previous pulsatile strategies presented only the envelope information, and discarded the FS of the signal. FSP was designed with the intention of overcoming some of the limitations of the envelope-based coding strategies (Arnoldner, et al., 2007). To do this, FSP utilises Channel Specific Sampling Sequences (CSSS) (Patent No. WO 01/13991 A1, 2001) to provide a temporal code to the most-apical one to three channels, and HDCIS on the remaining channels. As shown in Figure 2.10, CSSS analyses the bandpass filter output, and every time it crosses the zero point (from positive to negative), a series ultra-high-rate (typically 5-10k pps) biphasic stimulation pulses are initiated in the FSP channels (MED-EL Medical Electronics, n.d.; Patent No. WO 01/3991 A1, 2001). The repetition of these sequences represents the FS of the input signal and, therefore, enables the presentation of rapidly changing pitch details (Arnoldner, et al., 2007). These pulses are presented in the most-apical one to three channels, with the FS presented being limited to approximately 70 to 350 Hz. With the upper limit of phase locking in CI recipients possibly as low as 300 Hz, the presentation of higher frequency FS information may be inconsequential (Shannon, 1992; Zeng, 2002). One distinction to make with respect to terminology, is although the strategy is called FSP, the channels where CSSS occur are also commonly referred to as FSP channels.

It is important to note that in order to encode low-frequency FS information, the lower cut-off frequency in the filterbank is reduced from 250 Hz in the CIS+ strategy to 70 Hz in FSP. Therefore, if studies do not account for this difference between strategies when investigating how the addition of FS affects performance, they may find significant differences between strategies that are not due to the presentation of the FS, but rather are a reflection of the extended low-frequency filterbank boundary in FSP (Riss, Arnoldner, Baumgartner, Kaider, & Hamzavi, 2008; Riss, Arnoldner, Reiβ, Baumgartner, & Hamzavi, 2009).

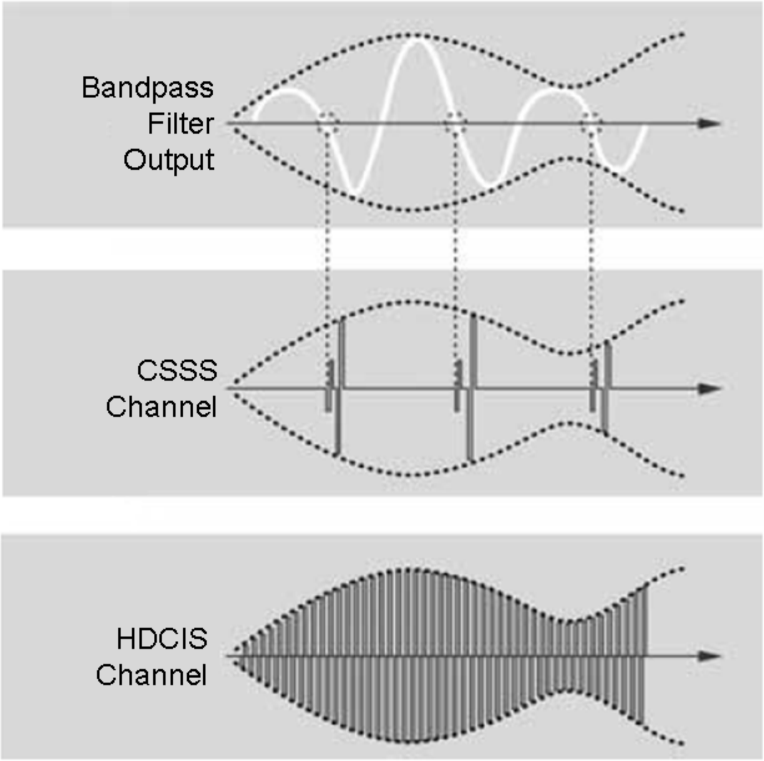

Figure 2.10: An example of the CSSS and HDCIS channel outputs in the FSP strategy. The CSSS channel shows a biphasic pulse train initiated when the waveform (FS) crosses the zero point of the axis, whereas the HDCIS channels use the envelope to modulate constant rate biphasic pulses (MED-EL Medical Electronics, n.d.). Adapted.

On the remaining channels, the frequency resolution of the CI recipient is increased through the implementation of 'virtual channels'. This exploits the summation of current from two adjacent electrodes to shift the sensation of pitch to a place between these electrodes (Arnoldner, et al., 2007). An example of the use of virtual channels is given in Figure 2.11 which shows how manipulating the proportion of current, referred to as current steering, to two adjacent electrodes can result in the perception of a pitch intermediate to the physical electrode positions.

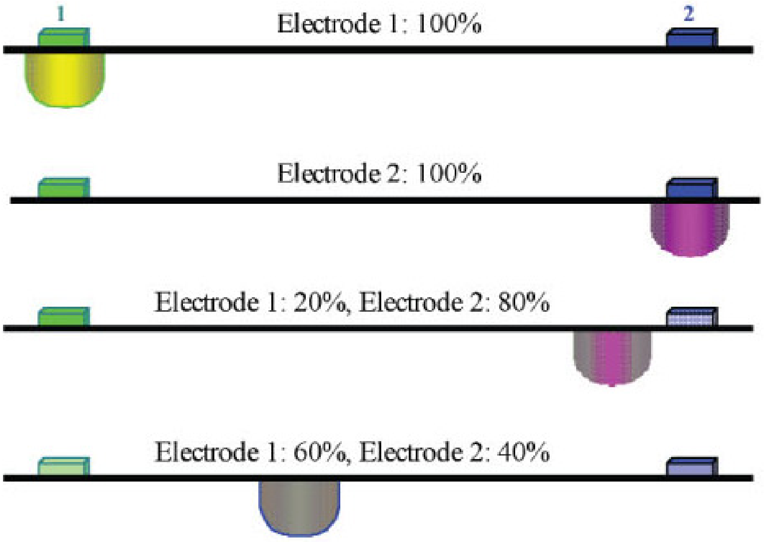

Figure 2.11: An illustration of the use of current steering to create virtual channels. The diagram shows how, when the proportion of current to electrodes 1 and 2 are altered, the perceived position of electrical stimulation (and therefore pitch) on the BM can be manipulated (Rawool, 2007).

2.2.5 Pitch Perception with Cochlear Implants

With respect to CIs, it is clear that difficulty in perceiving pitch is largely responsible for poor music perception (McDermott, 2004). As CIs appear to provide listeners with perceptually different or incomplete information about pitch, the ability to discriminate pitch differs from that of NH individuals (Vandali, et al., 2000). The key to improving music perception, therefore, appears to be the requirement of CI technology to transmit a more faithful representation of pitch (Gfeller, Witt, Stordahl, Mehr, & Woodworth, 2000b).

The three theories of pitch perception when applied to CIs do not apply in the same way as for NH individuals (McDermott & McKay, 1997). Place pitch perception is replicated by using multiple channel CIs with different electrodes stimulating different areas along the BM to exploit of the tonotopic organisation of the cochlea. Insertion of the electrode array along the entire length of the cochlea is not possible, however, with the current insertion depth equating to approximately 1.5 turns of the cochlea. This results in a frequency-place mismatch between the electrode being stimulated and the centre frequency for that place on the BM, which has been found to impede the accurate perception of pitch (Fu & Shannon, 2002; Kong, Cruz, Jones, & Zeng, 2004; Looi, McDermott, McKay, & Hickson, 2008b; Moore & Carlyon, 2005). There is also the potential for overlapping neural populations being stimulated by adjacent electrodes. The level of pitch discrimination is, however, nowhere near NH performance (e.g. Galvin, Fu, & Nogaki, 2007; Looi, et al., 2008b; Pijl, 1997), and in some cases pitch reversals are observed, where more-apical electrodes elicit a pitch higher than more-basal electrodes (Sucher & McDermott, 2007). The inability of CI users to discriminate pitch as well as NH individuals, is also due to the limited frequency resolution of CIs as a result of the limited number of wide filterbands with fixed centre frequencies. At low-frequencies, the harmonics are more likely to be resolved in a CI filterbank, as the filters are narrowly spaced at low-frequencies and widely spaced at high-frequencies. For high-frequencies with wide filterbands, several harmonics may fall within the same filter, but the combined waveform repeats at a rate corresponding to the F0 to provide pitch cues. This is another way pitch can be perceived by CI users. It should be noted though, that even if low-frequency harmonics are resolved, as CIs have fixed filterbands, the recipient would have difficulty discerning where within the filterband a harmonic falls (i.e. at the high- or low-frequency end), and, therefore, the ability to make reliable pitch judgements is affected (Looi, 2008; Looi, et al., 2008b). In addition to the limited frequency resolution of CIs place pitch, the perception of the stimulated electrodes (and therefore separate distinguishable pitch percepts) is also significantly limited by physiological factors such as the pattern and rates of nerve survival, brain plasticity, and electrical current spread in the cochlea, (Nie, et al., 2006), and physical constraints such as electrode spacing, location of individual electrodes relative to neurons, impedance of the return current pathway, and stimulation mode used (Kasturi & Loizou, 2007; Looi, et al., 2008b).

The perception of pitch using temporal information is possible, either by varying the rate of stimulation (Townshend, Cotter, Van Compernolle, & White, 1987), or by modulating the amplitude of the stimulus (Geurts & Wouters, 2001). Current clinical speech processing strategies do not vary their stimulation rate, therefore the only method of encoding pitch in the temporal domain is via the amplitude modulations present with unresolved harmonics in a filterband. It has been found that most CI recipients can perceive these modulations up to around 300 Hz (Shannon, 1983; Tong & Clark, 1985; Townshend, et al., 1987; Zeng, 2002), therefore it is possible for CI recipients to perceive low-frequency formant information with temporal cues.

Although pitch information can be provided in both the place and temporal domains, it is possible that the two mechanisms provide conflicting information. As mentioned previously, the shallow insertion of the array can create a mismatch between the centre-frequency of the CI filter corresponding to the electrode being stimulated, and the centre-frequency for that region of the BM. Recent research from CI recipients and NH listeners listening to spectrally shifted speech, suggests that over time the central auditory system can make adjustments to reduce this mismatch, to varying extents (Svirsky, Silveira, Neuburger, Teoh, & Suárez, 2004); however, CI users may place different weightings on the place and temporal codes, depending on the salience of each. Therefore, if the cues provide different information, the accuracy and reliability of pitch judgements could be unpredictably affected (Looi, et al., 2008b; Oxenham, Bernstein, & Penagos, 2004). McDermott (2004) provides more information on this.

The third form of pitch perception in NH individuals, place-temporal pitch, is not transmitted via CIs (Oxenham, 2008), as there is little or no neural detection of relative phase differences in the travelling wave along the length of the BM (Kong, Deeks, Axon, & Carlyon, 2009; Moore & Carlyon, 2005). Therefore, the ability of CI recipients to discern pitch by utilising this mechanism is essentially non-existent.

2.2.6 Timbre Perception with Cochlear Implants

Much of the discussion of pitch perception for CI recipients in Section 2.2.5 is relevant to timbre perception, as both pitch and timbre perception are related to the spectral envelope of the input signal; however, further discussion of the specifics of timbre perception is warranted. Timbre perception in music is most often assessed by instrument identification or subjective sound quality rating tasks. Studies asking CI recipients to rate the different qualities of musical sounds have shown that they typically report music to be sharp, scratchy, squeaky, tinny, booming, un-natural, mechanical, and noisy (Dorman, Basham, McCandless, & Dove, 1991; Gfeller, 1998; Gfeller, et al., 2000a; Gfeller, et al., 1998; Looi & She, 2010). Many of these descriptions suggest that sounds are higher in pitch than expected (e.g. 'tinny', 'squeaky', 'sharp'). This may be related to the fact that electrode arrays are only inserted into approximately the first 1.5 turns of the cochlea and hence the low-frequency spiral ganglion cells at the apical end of the cochlea are not stimulated by the electrodes.

Accurate timbre perception requires the perception of both the signal's envelope and the energy spectrum of its harmonic components (Looi, et al., 2008b). For example, changing the frequency and/or amplitude of the harmonics, or modifying features of the temporal envelope, such as the attack (or rise) time, will alter the perceived timbre (Handel & Erickson, 2004; Kohlrausch & Houtsma, 1989). Although current speech processing strategies extract the envelope information, the perception of the harmonic components is significantly limited. Existing CI processors only conduct a crude spectral analysis of the input signal using a limited number of wide filterbands. As discussed with relation to pitch perception (Section 2.2.5), the coding of spectral shape in CIs is limited as a result of insufficient stimulation channels, a tonotopic mismatch between the frequency of the CI's filter and the corresponding characteristic frequency in the cochlea, and/or a lack of precision in conveying temporal and spectral detail. Perceptual spectral smearing is also an issue for many CI users, possibly arising from factors such as wide current spread around the target electrodes, neural interactions, cochlear pathology, neural survival patterns and/or channel interactions (McDermott, 2004). Additionally, the harmonic information available in the FS is discarded.

In conclusion, the sound quality heard by CI recipients is typically poor and lacking in harmonic information. Speech processing strategies which better transmit aspects of this harmonic information may lead to higher ratings of sound quality from recipients.

2.2.7 Cochlear Implants and Quality of Life Measures

Cochlear implants have been shown to dramatically improve the quality of life (QOL) of recipients. In a study of elderly MED-El CI recipients aged between 64-85 years old, Anderson, D'Haese, and Pitterl (2006) found that 91% of respondents reported an improvement in QOL after surgery. The CI gave 89% of participants greater confidence, and 72% reported increased attendance at social functions. Similar results were found by Maillet, Tyler, and Jordan (1995), who found that a CI provided significant, positive changes in the QOL of patients and in their ability to communicate. Preliminary results from an inter-subject comparison of FSP and CIS with Mandarin speaking MED-EL CI recipients found slightly higher scores in QOL measures for FSP compared to CIS; however, this trend was not at the level of significance (Qi, et al., 2009). This suggested that improving the quality of a CI recipient's sound may lead to improved QOL.

Though CI recipients are generally very happy with their ability to hear again, this does not preclude the fact that the sound they hear is typically disappointing, and nothing like they remember it to be (Gfeller, 1998; Gfeller, et al., 2000a; Lassaletta, et al., 2007). Lassaletta et al. (2008b; 2007) investigated how the perception of sound quality was related to the QOL of CI recipients, and found there to be a direct link between increased sound quality ratings and increased QOL.

Chapter 3. Literature Review – Speech and Music Perception of Cochlear Implant Recipients

3.1 Speech Perception

Since 1980 there has been a steady improvement in speech recognition scores in quiet, at a rate of about 20% per five years (Zeng, 2004), and this improvement has now reached a plateau of maximal performance (Clark, 2008). Despite differences in speech processing strategies and electrode design, there appears to be no significant difference in performance between the recipients of the different devices currently available (Zeng, 2004).

In vocoder-based experiments with NH participants, it has been shown that slowly varying (< 50 Hz) temporal information (i.e. the envelope) can yield relatively high speech recognition performance with only a few channels, and asymptotic performance for speech recognition in quiet is reached with four to six channels of envelope information (Dorman, Loizou, & Rainey, 1997; Shannon, et al., 1995).

The number of channels of information required by CI recipients to understand speech in quiet has been directly measured in a number of studies. For example Fishman, Shannon and Slattery (1997) and Brill et al. (1997) found that speech perception in quiet increases when up to eight electrodes are stimulated but beyond this the recipient’s performance plateaus. Friesen, Shannon, Baskent, and Wang (2001) carried out similar work, by comparing how the number of channels of information affected speech recognition in 10 Cochlear Nucleus CI recipients and five NH participants. The authors also included an investigation into the effect of speech-shaped background noise on the number of channels of information required for speech recognition. They found that in the presence of varying signal-to-noise (SNR) ratios (0, +5, +10, +15 dB), the speech recognition abilities of the CI recipients plateaued with 7-10 stimulating electrodes, and that as the SNR decreased from +15 dB to 0 dB, the ability to understand speech decreased considerably. In comparison, the performance of the five NH participants with simulated speech stimuli continued to improve for up to 20 channels, irrespective of the SNR of the stimuli. This indicates that the CI recipients were unable to make use of all of the spectral cues presented via their CI, and depending on the complexity of the listening situation, different levels of information were required (Moore, 2008; Shannon, et al., 2004). For example, Figure 3.1 summarises the findings from a number of studies to show how many channels of spectral information are estimated to be required for good performance (> 80% correct) by NH listeners listening to CI simulations of varying complexity.

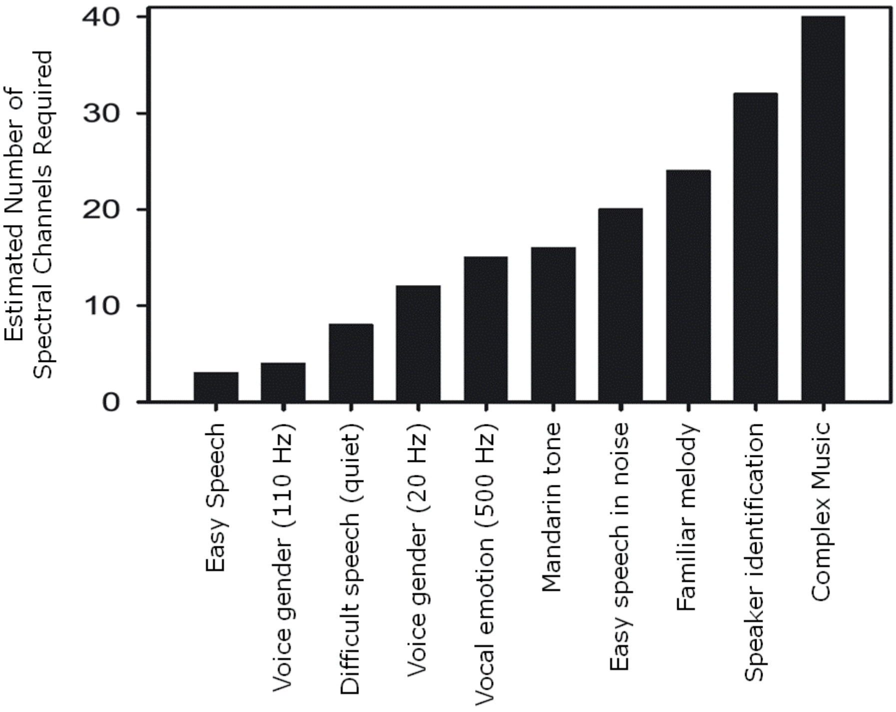

Figure 3.1: **The number of spectral channels required for different listening tasks.** As the complexity of the listening task increases, the estimated number of spectral channels required by NH listeners to CI simulations, to support good performance (> 80% correct) in a variety of tasks is shown (Galvin, Fu, & Shannon, 2009).

Riss et al. (2008) specifically studied if there was a difference between CIS and FSP with respect to the number of channels required for speech perception. They found no difference between the two strategies, and found similar results to other studies, with improved speech perception as the number of channels was increased from 2 – 12. Overall these studies indicate that for CI recipients, six to eight channels of envelope information is sufficient for understanding speech in quiet, with little or no improvement beyond this, and that performance in background noise is poor.

In a study comparing FSP and CIS for speech perception in quiet and noise (+5, +10 and +15 dB SNR), Riss et al. (2009) found that there was little difference between the two strategies in quiet. When in the presence of noise at +10 dB SNR, however, the average score increased from 32.43% to 56.25% ($p = 0.04$) when switched from CIS to FSP. This suggests that the additional FS information transmitted with FSP enhances the ability of recipients to separate the signal from noise.

The above speech based studies have been carried out with non-tonal languages. Tonal languages, such as Mandarin and Cantonese, require greater amounts of spectral information for accurate speech perception, and current speech processing strategies do not appear to provide this level of spectral acuity (Fu, Hsu, & Horng, 2004). Preliminary studies of Mandarin speech perception with FSP, have found that after an extended period of acclimatisation to FSP of at least 6 weeks, speech recognition abilities with FSP were significantly higher than with CIS for 12 adult MED-EL CI recipients (Qi, et al., 2009).

3.2 Music Perception

Comprehensive reviews of music perception through CIs are provided by McDermott (2004) and Looi (2008), however, an overview of the current findings is provided below.

Now that speech recognition for non-tonal languages is at the point where consistently high scores are attainable by the majority of patients, much of the focus of CI research and development has shifted to the area of music perception and appreciation. Current processing strategies encode insufficient spectral information for optimal music appreciation or accurate perception (Kong, et al., 2004); however, music appreciation cannot be simply assessed as a function of perceptual accuracy (Gfeller, et al., 2008). For example, when hearing unfamiliar music, listeners base their emotional reactions largely on the tonal qualities (e.g. timbre, melody, harmony, etc) of musical pieces (Trainor, 2008).

3.2.1 Self-reported Listening Habits and Music Appreciation of Cochlear Implant Recipients

Several studies have investigated the self-reported differences between pre- and post-surgery listening habits, perceived quality of sound, and enjoyment of listening to music. For example Gfeller et al. (2000a), Leal et al. (2003), Lassaletta et al. (2008a, 2008b; 2007), Mirza et al. (2003), and Tyler et al. (2000) used questionnaires to investigate the music listening habits of CI recipients across a variety of cultures and implant types. The combined findings of these studies show that CI recipients listen to music less than before deafness, musical sound quality is typically rated as being less pleasant than before implantation, enjoyment of music is decreased post-surgery, and music tends to be more difficult to follow.

3.2.2 Perception of Rhythm

The ability of CI recipients to perceive rhythm has been investigated by a number of studies (e.g. Cooper, Tobey, & Loizou, 2008; Gfeller & Lansing, 1991; Kong, et al., 2004; Leal, et al., 2003; Looi, McDermott, McKay, & Hickson, 2008a; Schulz & Kerber, 1994). Although the methodologies of these studies differ, the findings consistently report that CI recipients perform similarly to NH listeners on rhythm perception tasks. Similarly, in studies of melody recognition it was found that rhythmic information is important for CI recipients when recognising familiar melodies (Fujita & Ito, 1999; Kong, et al., 2004; Schulz & Kerber, 1994). Therefore, it is clear that the envelope extraction rationale employed by current speech processing strategies allows for accurate perception of rhythmic information.

3.2.3 Perception of Pitch

Pitch perception has been investigated by a number of studies, either by presenting puretones or complex tones. It is generally accepted that when listening to western music the ability to discriminate a tonal difference of one semitone, which is equivalent to a frequency change of approximately 6%, is necessary for adequate melodic perception (Nobbe, et al., 2007; Pretorius & Hanekom, 2008). This level of accuracy in CI recipients is, in most cases, not possible, with studies finding that resolution of less than a few semitones is not consistently observed in the free-field (Pijl, 1997). Large inter-subject variability in the ability to discriminate pitch differences is also commonly observed (Galvin, et al., 2007; Looi, et al., 2008b; Pijl, 1997). For example, Galvin, Fu and Nogaki (2007) investigated the ability of 11 Clarion, Cochlear Limited (CI22 and CI24), and MED-EL CI recipients to identify nine different melodic contour patterns consisting of five notes. The interval size between successive notes on each melodic contour was varied between 1 to 5 semitones. The speech processing strategies used by the participants were the HiRes, ACE, SPEAK, and CIS+ strategies. The study found that there was great inter-subject variability, with no clear advantage for any particular CI device or processing strategy. Top performers were able to correctly identify most melodic contours when the interval size between successive notes was at least 2 semitones, whereas poor performers were only able to identify 40% or less of the contours, even when there were 5 semitones between successive notes.

Gfeller et al. (2002a) investigated 49 CI recipients using either a Clarion, MED-EL, or Cochlear Limited device (with the CIS or SPEAK speech processing strategies), and 18 NH participants in their ability to pitch-rank complex tones. They found the NH participants had a mean minimum threshold of 1.13 semitones with a range of 1-2 semitones, whereas the CI participants showed a minimum threshold of 7.56 semitones with a range of 1-24 semitones. In a second part to this study, three NH participants and 16 CI recipients participated in a further puretone discrimination task in order to examine the relations between puretone and complex tone discrimination. The participant's just noticeable difference (JND) for puretones was obtained at five frequencies by asking the participant to indicate which of four intervals presented contained a tone that was 'different in pitch' to the others. Results showed that the NH participants had frequency difference limens of less than 0.01, whereas the CI recipients had variable results ranging from 0.02 to 1.0 frequency difference limens.

Sucher and McDermott (2007) compared the pitch perception skills of eight Cochlear Limited CI recipients (using either a CI22 or CI24 device), and 10 NH listeners. A pitch-ranking task was used with sung vowel stimuli, where the intervals were either 1 or 6 semitones apart. Significant differences between the NH and CI scores for both the 1 semitone and 6 semitone interval were found, with the NH participants scoring 81.2% and 89.0% correct respectively, and the CI participants scoring 49.0% and 60.2% correct.

In a melodic contour identification task, Galvin et al. (2008) used six different instruments (organ, glockenspiel, trumpet, clarinet, violin and piano) to play nine different melodic contours. The authors found that there was considerable inter- and intra-subject variation depending on which instruments were used, with the organ producing the best average performance (70.4%) and the piano the worst (54.2%). Thus it appears that not only is it difficult for CI recipients to differentiate between instruments, but also that the ability to discriminate pitch variations is influenced by which instruments are being played.

The first results presented on the FSP speech processing strategy have shown CSSS encoding of low-frequency FS to have some benefit in pitch perception. A comparison study of an unstated number of MED-EL CI recipients using FSP and CIS+ found the average JND in pitch, when listening to synthetic waveforms, to be 10% smaller with FSP than with CIS+ (Mitterbacher, Zierfofer, Schatzer, & Kals, 2005a). Mitterbacher et al. (2005b) analysed the pitch scaling abilities of five MED-EL CI recipients using FSP and an experimental version of CIS+ which had an extended low-frequency filterbank in order to match that of FSP. The authors found that below 300 Hz, which is the domain of CSSS, FSP provided both place and temporal pitch cues, whereas CIS+ provided place cues only. This was shown with the pitch judgements for FSP, of acoustically presented puretones relative to a constant rate sinusoidal burst on the third electrode (1515 pps), being superior to CIS+ below 300 Hz, and similar above 300 Hz. Other studies carried out which have found results similar to those discussed above include Lassaletta et al. (2008b), Leal et al. (2003), Gfeller et al. (2007), Fujita and Ito (1999), and Schulz and Kerber (1994).

It is important to note that in the studies mentioned above, the stimuli were presented via a freefield speaker, with participants using their own speech processor and everyday device settings to listen to the stimuli. Studies examining the perception of pitch with direct stimulation have produced results which, although not at the levels of NH individuals, are higher than when the sounds have been processed by the speech processor (e.g. McDermott & McKay, 1997; Pijl, 1997; Pijl &

Schwarz, 1995). Therefore it appears that the limitations imposed on electrode stimulation by speech processing strategies are likely to contribute to the poorer ability of CI recipients to percieve pitch accurately. One study which looked at the pitch perception abilities of MED-EL CI recipients when using experimental versions of 10 channel FSP and CIS strategies is worth mentioning (Krenmayr, et al., 2009b). The FSP strategy used an increased frequency range for the CSSS analysis of 100 – 811 Hz, which was used to stimulate four FSP channels, with the remaining six channels using CIS (covering the frequency range of 811 Hz – 8500). The CIS strategy used 10 CIS channels, spread across the 100 Hz – 8500 Hz frequency range. The task asked the participants to choose whether a tone was higher or lower in pitch compared to one of four reference tones, with the authors finding that as the frequency of the reference tones increased to the cross-over frequency between CSSS and CIS stimulation (811 Hz), the ability of the participants to distinguish the tones decreased. They therefore concluded that FS stimulation from the experimental FSP strategy expanded the range in which the recipient could accurately perceive pitch, and therefore provided the participants with a more comprehensive impression of the sound.

In summary, the collective findings of numerous studies on the pitch perception show that the ability of CI recipients to utilise pitch cues conveyed via currently available speech processing strategies is poor, although the inclusion of some FS temporal information may provide some additional limited assistance.

3.2.4 Perception of Melody

The ability of CI recipients to recognise and distinguish melodies is also poorer than for NH listeners (Gfeller, et al., 1998), although performance in such tasks can be heavily influenced by factors such as the presence or absence of extraneous cues such as lyrics, rhythm, visual cues, and prior musical knowledge (Drennan & Rubinstein, 2008; Looi, et al., 2008a). Fujita and Ito (1999) assessed the recognition of nursery songs that were familiar to eight Cochlear Limited CI recipients using either the now-obsolete SPEAK or MPEAK processing strategies. Subtests of melody recognition were carried out by presenting four tunes with and without vocal accompaniment, and asking participants to identify these in both an open- and closed-set format. The results showed that the participants could recognise, on average, 39% of the melodies with lyrics in the open-set condition, and 53% in the closed-set condition. When the melody line was presented without accompanying vocals, the recognition scores dropped to 17% correct in the open-set and 21% in the closed-set conditions. In another subtest, when participants were asked to distinguish between nursery songs with similar rhythms in the same pitch range, their scores were at the chance level. Further studies by Galvin (2007), Kong et al. (2004), Leal et al. (2003), Gfeller et al. (2002a; 2000b) and Schulz and Kerber (1994) have similarly assessed the abilities of CI recipients to recognise familiar melodies. The combined results of these studies similarly confirm that melody recognition for CI recipients is poor, and significantly influenced by rhythmic cues and the presence of lyrics or vocal cues.

The studies mentioned so far have consisted of simple melodies typically played by a few or one instrument such as a piano. Some studies have attempted to ascertain a more 'real world' assessment of the melody perception and identification of CI recipients by using commercially available songs, as this would be more reflective of the everyday experiences of CI recipients. In Gfeller et al.'s (2005) study, the authors investigated the ability of participants to recognise 'real world' musical excerpts from the pop, country and western, and classical genres. The primary aim of the study was to examine how accurately CI recipients were able to recognise previously-familiar tunes. In the task, the participant was asked if they recognised certain pieces of music. If they answered yes, further questioning was carried out to ascertain the level of familiarity. The authors found that as a group, the CI recipients did not score higher than 20% correct across the three genres, whereas the NH participants' averages were between 43% and 60% correct. They also found that song familiarity was affected by genre for both NH and CI participants, where the pop genre contained a much higher proportion of familiar songs than the other genres.

Cooper, Tobey and Loizou (2008) approached the area of melody recognition from a slightly different perspective, as they recognised that familiar melody identification is influenced by extraneous factors such as duration of deafness, auditory memory, and music listening history. In other words if a participant had been profoundly deaf for a long period of time, or did not listen to music prior to deafness, they were familiar with fewer songs than other participants. To account for this, the authors used the Montreal Battery of Evaluation of Amusia (MBEA) test (Peretz, Champod, & Hyde, 2003) which uses melodies to assess a variety of music perception skills. At the conclusion of testing the MBEA test asks the participant to identify from a set of melodies, those that were used in the previous assessments; thus the confounding factors in melody identification mentioned above are minimised. They found that the 12 CI recipients in the study were better able to remember the 'rhythm-dominant' melodies than the 'pitch-dominant' melodies; however, the overall ability to remember melodies was still below that of NH listeners.

In summary, the melody recognition abilities of CI recipients are poor, with even the best performers struggling to attain similar levels to the average NH participant. Rhythm and lyrical cues are heavily relied upon to recognise melodies, and when these are removed many CI recipients perform at the chance level.

3.2.5 Perception of Timbre

The perception of musical timbre, and the ability of CI recipients to identify particular differences in timbre has been the focus of a number of studies. These studies typically require the participant to identify musical instruments, with results showing that many CI recipients struggle with this task, particularly when the instruments have similar spectral properties. Gfeller et al. (1998) compared 28 Clarion CI recipients utilising the CIS processing strategy to 41 NH listeners, on a closed-set instrument identification task. Of the 12 instruments in the closed-set response choices, only four were actually presented to the listeners: the clarinet, piano, trumpet and violin. These were chosen as they had a similar frequency range and encompassed the four main instrumental families; woodwind, pitched percussion, brass, and strings. The NH group's average for each instrument ranged from 66% – 100% correct, which was significantly better than the CI group's averages of 20% – 56% correct. For both groups the piano was most easily recognised instrument.

A later study by Gfeller et al. (2002c) expanded on this by assessing the timbre perception and appraisal of 51 CI recipients using either a Clarion, Cochlear Limited, or Ineraid device, along with 20 NH participants. The speech processing strategies utilised by the CI recipients were CIS, SPEAK, and an un-named analogue strategy. Participants were required to listen to and identify eight different musical instruments, which were separated into three F0 ranges (low, mid, and high), and the four instrumental families in the Gfeller et al. (1998) study. Similar to the findings of the previous study, the Gfeller et al. (2002c) study found that the NH participants achieved a mean score of 90.9% correct, whereas the CI recipient's average score was 46.55%. The range of scores for the CI group (11% - 100%) was much larger than for the NH group (67% - 100%), with the NH participants tending make within-instrument family confusions (e.g. mistaking violin for cello, or clarinet for saxophone), whereas the CI recipients showed no obvious pattern to their errors.

Part of the previously discussed study carried out by Leal et al. (2003) involved a timbre perception task which required 29 CI recipients to identify the instrument playing a simple melody. The instruments used were the trombone, piano, and violin, playing the same melody at the same tempo and loudness level. The study found that 68% of the participants were able to identify all three instruments correctly, which is higher than other studies in the literature. Reasons for the higher scores could include the limited number of instruments tested, and/or the fact that the three chosen instruments generate sound in three different manners, each with their own unique onset and offset cues.

The Looi et al. (2008a) study of pre- and post-surgery performance found that the timbre perception of nine CI recipients was better after implantation, however the maximum average score achieved in the simplest, single instrument condition, was still only 65% correct. As the complexity of the stimulus increased by adding background music, the mean performance decreased to 55% correct.

In summary, the performance of CI recipients on timbre discrimination tasks has been found to be poor. The reasons for this would be similar to those for pitch perception. Timbral information is encoded in the FS (Arnoldner, et al., 2007; Drennan & Rubinstein, 2008), therefore the current envelope extraction rationale implemented in CI systems contributes significantly to this poor performance. Coupled with this, the limited spectral resolution of CIs to between 12 -24 channels depending on the manufacturer, also leads to reduced timbral perception.

3.2.6 Appraisal of Timbre or 'Liking'

In many of the studies discussed in the previous section, an assessment of the subjective quality of the timbre was also carried out, either through a measure of 'liking', or by assessing specific timbral qualities such as those mentioned in Section 2.1.1. The assessment of identification and perceptual accuracy is different to appraisal and ratings of sound quality, which although they are often incorporated together into studies, are separate areas of CI research and provide different information. For example, knowing the name of an instrument or melody does not necessarily mean that one will like it; similarly one may favourably rate a song even if they have not heard it before. Hence, although poor music perception may lead to poor appraisal, it is important to note that music appraisal cannot be addressed solely as a function of perceptual accuracy.

Gfeller et al. (2002c) assessed the general likeability, as well as more specific timbral qualities, of a variety of musical instruments. For the specific timbral qualities, the visual analogue scales (VAS) of dull-sharp, compact-scattered, and full-empty were used. In the likeability task, 11 NH listeners rated their 'liking' of the stimuli, which was compared to 48 CI recipients using either the Clarion, Ineraid, or CI22M devices. Results showed that there was a significant difference between the NH and CI groups in their appraisals of each instrumental family, which was also affected by the stimuli's frequency range. The general trend was that the NH participants had higher ratings for 'liking' than the CI group, and the CI group tended to like the sound of the low-to-mid frequency instruments over higher frequency instruments. In rating the different timbre dimensions, 59 CI recipients rated the high-frequency instruments as more scattered and less brilliant, and the string family to sound significantly more scattered ($p < 0.0014$), less full ($p < 0.0001$), and more dull ($p < 0.0001$) compared to the 24 NH listeners ratings. This study agreed with a previous study carried out by Gfeller et al. (1998) which used a VAS for participants to assess the 'likeability' of four musical instruments. Analysis revealed that the implant recipients displayed a smaller range of likeability scores (38.83% - 52.33%) when compared to NH participants (40.17% - 72.12%).

Looi et al. (2007) compared the music quality ratings of 24 hearing aid (HA) users with 15 Cochlear Limited CI recipients, who were using either the SPEAK or ACE processing strategies. Nine of the HA users were on the waiting list (WL) for receiving a CI. The test required the participants to rate the pleasantness of 48 extracts of music from 1 to 10, where 1 was 'very unpleasant' and 10 was 'very pleasant'. They found that neither device enabled highly satisfactory music appreciation, and no significant differences in ratings between the HA users who were not on the WL and the CI recipients. Significantly lower ratings were given for the HA users on the WL when compared to either of the other groups. Once the WL participants were implanted, the test was conducted again, and results showed that the quality ratings improved significantly between pre- and post- surgery measurements. The authors proposed that this could be due to either the inability of the HA to compensate for the significant cochlear hearing loss, the different in the information provided by the HA and the CI, or personal bias of the participants who may have felt that a CI was a superior device to a HA.

The effect of familiarity and complexity on appraisal ratings was investigated by Gfeller et al. (2003). Again, VAS for appraisal (like-dislike) and complexity (simple-complex) were used with 36 different test items, 12 each of country and western, pop, and classical. The participants consisted of 36 NH adults, and 66 experienced CI recipients using a range of devices and processing strategies. The results showed that the NH participants rated their liking of the classical and pop pieces higher than the CI group, and that familiarity with the item led to a higher rating of sound quality for the NH participants. This trend was not observed in the CI group, with the authors suggesting that this was due to the fact that CI recipients may not have been able to recognise songs, even if they showed that they were familiar with them. When rating the complexity of the test items, both the NH and CI groups rated the classical genre as the most complex, followed by the pop, then country and western.

In summary, research shows that the quality of musical sounds transmitted through CIs is generally rated poorly, with the highest ratings for simple, rhythmic tunes, and lowest for complex tunes which CI recipients typically describe as unpleasant.

3.2.7 Correlations with Subject Variables

Demographic information such as age, duration of deafness prior to implantation, time with the device, musical training, and speech perception skills are commonly collected and analysed in studies of CI recipients. Some of the factors which have been identified to potentially affect the perception and appraisal of music are:

- Longer duration of deafness prior to implantation leads to decreased perceptual accuracy and song recognition (Gfeller, et al., 2005; Gfeller, et al., 2002a),
- The ability to recognise melodies, in most cases because of associated lyrics or rhythm cues, leads to improved appraisal (Fujita & Ito, 1999; Gfeller, et al., 2008).
- The age of participants, with accuracy, appraisal ratings and/or song recognition decreasing with age (Gfeller, et al., 2000a; Gfeller & Lansing, 1992; Gfeller, et al., 2005; Gfeller, et al., 2002a; Gfeller, Woodworth, Robin, Witt, & Knutson, 1997).

- Frequent music listening post-implant correlates with improved perception and appraisal. However, it is unclear whether the CI recipients' higher scores are due to their post-implant listening habits, or because those who can perceive music well are more likely to listen to music regularly (Gfeller, et al., 2000a; Gfeller, et al., 1998; Gfeller & Lansing, 1992; Gfeller, et al., 2005; Leal, et al., 2003).

Factors which have not been shown to impact on music perception include:

- Device or processing strategy used (Galvin, et al., 2007; Gfeller, et al., 2008; Gfeller, et al., 2005; Leal, et al., 2003).
- Experience with a device (Gfeller, et al., 2005; Looi, et al., 2008b),
- Pre-surgery music experience (Gfeller, et al., 1998; Gfeller, et al., 2005; Gfeller, et al., 1997; Looi, et al., 2008b).
- Speech perception scores for songs with no lyrics (Gfeller, et al., 1998; Gfeller, et al., 2008; Looi, et al., 2008b).

The factor of formal musical training prior to implantation has provided mixed results, with Gfeller et al. (2000a; 1998; 1997) finding that formal music training does not correlate highly with perceptual accuracy or appraisal, whereas the more recent Gfeller et al. (2008) study found a moderate positive correlation.

3.3 Conclusions

In conclusion, CI recipients generally report lower levels of music enjoyment when compared to pre-deafness listening habits (Gfeller, et al., 2000a; 2008a, 2008b; Lassaletta, et al., 2007; Leal, et al., 2003; Mirza, et al., 2003; Tyler et al., 2000). This decrease in enjoyment is in part due to the difficulties in accurately perceiving musical elements such as pitch and timbre. The reasons for this reduced perceptual accuracy include limitations of the CI device and it's technology (e.g. Pijl, 1997), issues related to electrical stimulation of the cochlea and electrically-evoked hearing (e.g. Shannon, 1983; Shepherd, Hatsushika, & Clark, 1993), physiological considerations associated with a severe to profound sensorineural hearing loss (Hopkins, Moore, & Stone, 2008; Moore, 2008; Nadol Jr, Young, & Glynn, 1989), and the reduced ability for CI recipients to utilise FS cues (Kong, et al., 2009).

Some of the poor performance of CI recipients in music perception and appraisal tasks appears to be due to limitations in signal processing, in addition to physiological deficiencies (eg Pijl, 1997). Therefore the need for improved representation of the acoustic signal is required in future speech processing strategies.

Chapter 4. Overview of the Study

4.1 Rationale

There are a host of tests of music perception accuracy for CI recipients, however, there are few music sound quality assessments available. As mentioned in Section 3.2.6 , studies reporting music appraisal ratings have either used a written questionnaire format, or have asked participants to rate the sound quality of excerpts that were used in perceptual accuracy tasks. That is, the stimuli played to participants were primarily selected for a different task (i.e. identification). No published study has focussed solely on music appreciation ratings, from CI recipients, obtained whilst listening to specifically chosen songs selected to assess appreciation and sound quality ratings only. As such, although a host of music perception test batteries are available, (e.g. MBEA, PMMA, UW-CAMP, AMICI, and MCI)[2] there is no test battery designed for assessing music quality ratings.

Due to previously mentioned issues related to poor music perception and appreciation of CI recipients, manufacturers have been developing new speech processing strategies to try to improve music listening. Hence effective appraisal-based tools are necessary to assess how these new processing strategies *sound* to CI recipients. One such new strategy is FSP, which is currently the default strategy for the MED-EL MAESTRO® CI system. As mentioned, the FSP strategy was developed on the premise that providing the FS information to the lower-frequency channels of

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[2] MBEA = Montreal Battery of Evaluation of Amusia (Peretz, et al., 2003)

PMMA = Primary Measures of Music Audiation (Gordon, 1979)

UW-CAMP = University of Washington Clinical Assessment of Music Perception (Nimmons, et al., 2008)

AMICI = Appreciation of Music in Cochlear Implantees (Spitzer, Mancuso, & Cheng, 2008)

MCI = Melodic Contour Identification (Galvin, et al., 2007) the CI could improve the recipients' ability to perceive pitch changes and timbre variations. Although the developers of FSP claim that it provides better sound quality for listening to music (MED-EL Medical Electronics, n.d.), there has been limited research conducted to investigate this.

4.2 Aims and Hypotheses

The overall aims of this study were to develop a music quality test rating battery (MQRTB) for use with New Zealand (NZ) and Australian CI recipients, and use this to assess how MED-EL CI recipients find the sound quality of music with FSP in comparison to MED-EL's previous default clinical strategy, HDCIS.

The research questions posed by this study are as follows:

1. Does familiarity with a speech processing strategy affect the musical quality ratings?
2. Do CI recipients notice a significant difference between FSP and HDCIS when listening to music and if so, what aspects of the sound are different?
3. Does song familiarity affect the preference ratings of music in CI recipients?
4. Does music genre affect the preference ratings of music in CI recipients?

It is hypothesised that:

1. Familiarity with either FSP or HDCIS will affect the quality ratings of CI recipients, with the processing strategy the participants are acclimatised to being preferred in music quality ratings.
2. CI recipients will prefer the sound of FSP over HDCIS on the rating scales of pleasantness, naturalness, richness, fullness, sharpness, and roughness.

3. CI recipients will rate the sound quality of familiar songs to be higher than obscure songs.
4. CI recipients will rate modern songs higher than classical, country and western, or common songs.

Chapter 5. MQRTB Development

This chapter is separated into two sub-sections, in which the methods (Section 5.1) and results (Section 5.2) for the development of the MQRTB are presented consecutively.

5.1 Methods for the MQRTB Development

The MQRTB was developed to assess the sound quality of music heard by the listener. The songs comprising the MQRTB were carefully chosen in order to account for the goals of this study, in particular those pertaining to song familiarity and genre. It was decided that in order to make the test battery informative, yet time efficient, 10 songs across five different categories and genres would be incorporated. An obscure and familiar piece for each of modern (pop/rock), classical, common (such as a national anthem or iconic melody), and country and western genres were supplemented with two pieces of the participant's favourite music.

Phase one involved the selection of potential songs for inclusion in the MQRTB, and assessment of their familiarity. The results of this verification procedure were used to ascertain the final selection of songs included in the MQRTB. Phase two assessed the length and complexity of the MQRTB with self-reported NH individuals, and phase three pilot tested the MQRTB prior to its use for the FSP versus HDCIS comparison study.

5.1.1 Phase One: Verification of 'Familiar' and 'Obscure' Pieces With the General Population.

For phase one, in each genre, three suitable pieces were chosen for the 'familiar', and three for the 'obscure' categories (24 songs in total). These selections were based on the inclusion criteria outlined in Appendix A, with the familiar items matched to the obscure items based on their musical characteristics such as band type and sex of vocalist. All category items contained lyrics except for those in the classical genre. In the 'common' genre some of the lyrics were not in English. Each song recording was taken from commercially available compact disc (CD) recordings, with no modifications made to the pieces for the pilot testing phase.

Once the 24 songs were selected (Appendix B), a CD and response sheet (Appendix C) was sent to 67 participants, whose details are shown in Table 1 below. Participants were selected in an attempt to match the average age and demographics with that of the population of CI recipients who were eligible for the FSP versus HDCIS part of this research (Section 5.2).

Table 1: Participant details for phase one of the MQRTB development.

Number of Respondents	Mean Age (SD)	Country of Residence		Country of Birth		
		NZ	Aust.	NZ	Aust.	Other
67	55.77 (15.30)	42	25	39	15	11

The participants were asked to listen to each piece once and answer a few questions about the songs, such as if the song was familiar (Yes/No), and to name the song title, artist and/or composer if possible. Demographic information about the individuals was also collected to ascertain whether the sample was reflective of the population to be used in the FSP versus HDCIS study. The ability to name identifying features about the song (e.g. composer or song title) was used to differentiate between equally familiar songs in the final selection of the MQRTB items. Participants were also instructed to make their judgments of familiarity immediately without referring to any supplementary material and/or doing additional research. They were made aware that they were not being tested; the purpose this task was to establish the level of immediate familiarity of the songs.

5.1.2 Phase Two: Pilot Testing of the MQRTB Procedure

The results from phase one were analysed, with the pair of songs which had the largest proportion of participants recognising the 'familiar' item but not recognising its ‘obscure’ equivalent selected for use in the MQRTB (8 songs total). The songs selected are provided in Appendix D.

To assess the practicality and length of the MQRTB rating task, phase two involved pilot testing of the computer based rating task (O’Beirne, 2009) with 3 male and 7 female participants (mean age 41.9 years, SD = 9.85), with self-reported NH, who were recruited from friends and family of students and staff at the University of Canterbury. A detailed description of the methodology for the FSP versus HDCIS MQRTB task is provided in section 6.1.3. In order to replicate the CI study for which the MQRTB was being designed, this pilot test used an altered MQRTB methodology asking the participants to compare two markedly different equaliser settings on the stereo. In other words, the participants listened to the same song under two different conditions and rated the different qualities of the sound. A standard explanation and demonstration of the ratings scales was developed for this phase, in which the assessor described and demonstrated the rating scales, and how to use the touchscreen.

Overview of the MQRTB Rating Scales

For each item in the MQRTB, the participant was asked to make ratings on six scales, which were anchored with antonym pairs used to describe the specific timbral qualities of the stimuli, and presented on a touch-screen using a specially written program (O'Beirne, 2009). The scales were based on the theory of VAS rating scales (Freyd, 1923) with all descriptors based on research carried out by von Bismark (1974a, 1974b), Looi et al. (2007), Looi and She (2010), and Gfeller et al. (1991; 2002c).

The first three scales were true VAS with two contrasting adjectives plotted in the semantic differential space equidistant from a neutral centre point (Heise, 1969). They were anchored with the following antonyms: (1) unpleasant-pleasant; (2) unnatural-natural; and (3) tinny-rich, with the perfect sound being rated by placing the pointer at the extreme right of the scale. The second three scales were modified VAS using the antonym pairs: (4) emptier-fuller; (5) duller-sharper; and (6) smoother-rougher, with mid-points labelled with the descriptor 'exactly as I want it to sound'. The midpoint was provided as a reference for the participants to make their judgement from, where moving the marker to the left or right of the midpoint indicated a deviation away from the ideal sound towards the endpoint descriptors. These scales are referred to as Mid-point scales (MPS). For example, Figure 5.1 shows on the fullness scale, if the participant left the marker at the midpoint (1) this meant that the sound was exactly as they wanted it to sound, whereas marking to the left of the midpoint (2) meant that the sound was emptier than they would like, and to the right (3) indicated a sound that was fuller than they would like. The positions relative to the mid-point indicate that marker position 2 is a more-preferable sound than position 3, as it is closer to the mid-point. Screenshots of the scales used are shown in Appendix E.

Figure 5.1: **An example of how marker placement on the fullness rating scale is interpreted.**
If the participant left the marker at position 1, this meant the sound was exactly as they wanted it to sound, position 2 means the sound is emptier than they would like, and position 3, fuller than they would like it to sound. Note that position 2 is closer to the mid-point than 3, and therefore indicates that a rating at position 2 has a more-preferable sound than position 3.

5.1.3 Phase Three: Pilot Testing of the FSP Versus HDCIS Comparison Study Procedure

In this phase, pilot testing of a complete testing session of the FSP versus HDCIS comparison study with four MED-EL CI recipients (Mean age = 52.0, SD = 15.1) was carried out, as a further check of task suitability and length. The participants used in this pilot study were selected from the pool of MED-EL CI recipients who did not fulfil the inclusion criteria requiring a stable programme for the duration of the study, as they were still attending regular re-programming appointments. These participants were suitable for the pilot study as the testing was completed in a single session.

5.2 Results for the MQRTB Development

5.2.1 Phase One: Verification of 'Familiar' and 'Obscure' Pieces with the General Population

Phase one was a questionnaire and CD based task used to determine the level of familiarity of 28 pre-selected songs to aid in the final selection of the MQRTB items. The participants were asked to indicate if they 'knew, 'did not know' or were 'unsure' of each item on the CD. The results are presented in Figures 5.3 - 5.5. For each genre (classical, modern, country and western, and common), the pair of songs which had the largest proportion of participants recognising the 'familiar' item but not recognising its obscure equivalent was selected for the MQRTB. These are shown in red on the figures below, and are listed in Appendix D.

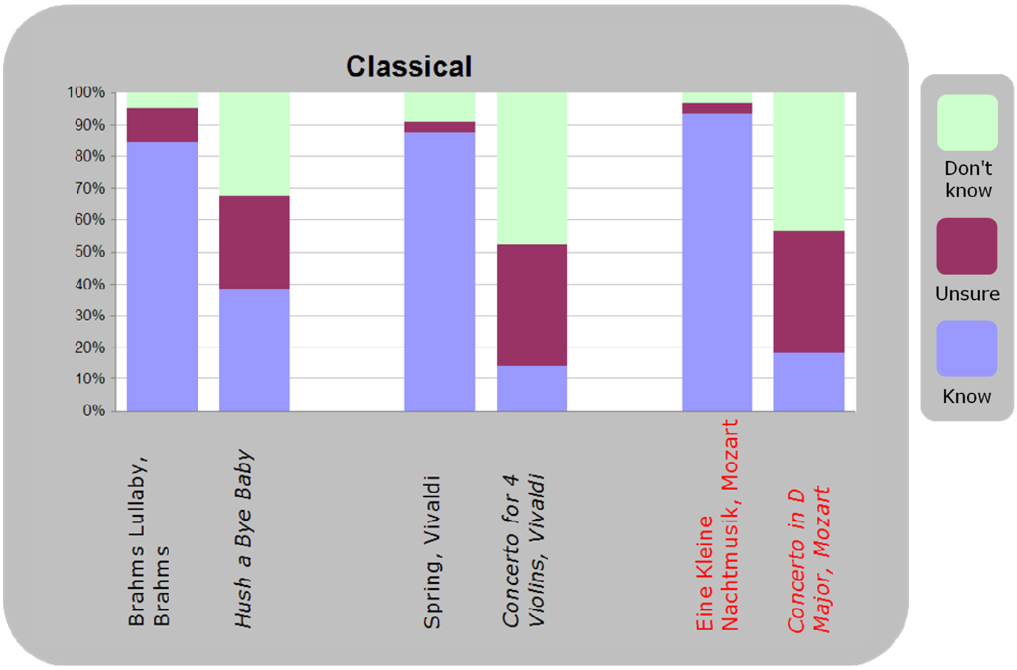

Figure 5.2: **The matched songs selected for the classical genre.** The songs are shown in their familiar-obscure pairs, with the obscure items in italics. The pair selected for the MQRTB is highlighted in red.

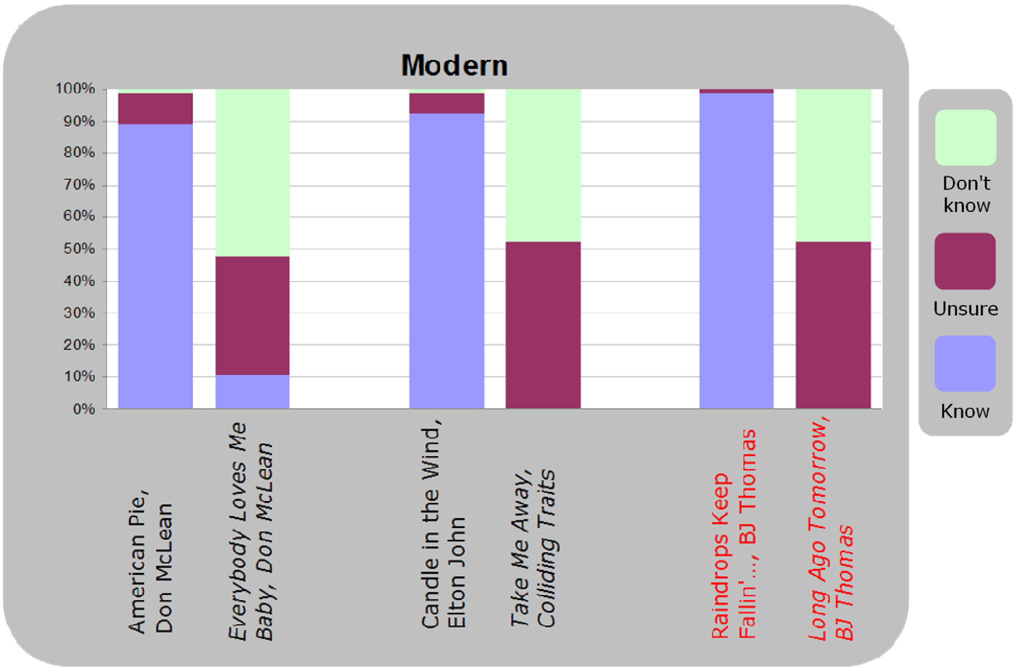

Figure 5.3: **The matched songs selected for the modern genre.** The songs are shown in their familiar-obscure pairs, with the obscure items in italics. The pair selected for the MQRTB is highlighted in red.

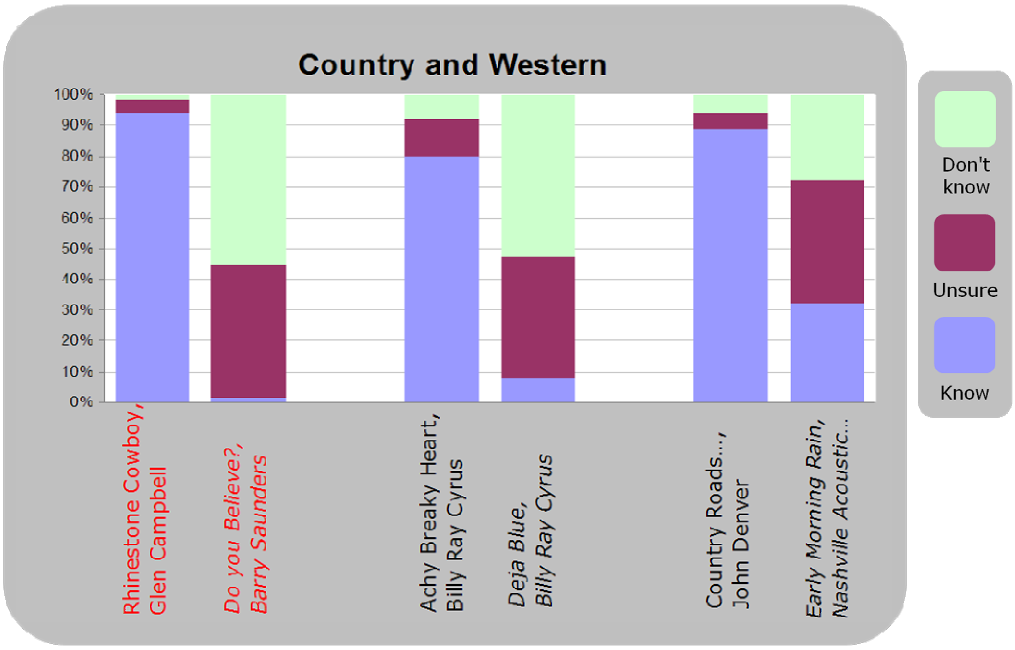

Figure 5.4: **The matched songs selected for the country and western genre.** The songs are shown in their familiar-obscure pairs, with the obscure items in italics. The pair selected for the MQRTB is highlighted in red.

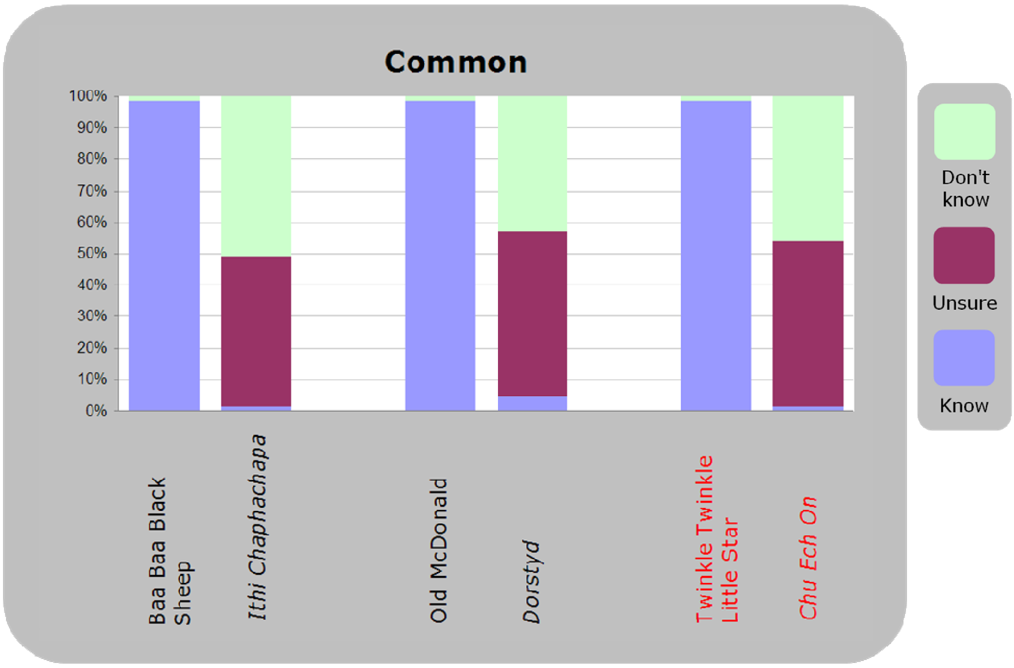

Figure 5.5: **The matched songs selected for the common genre.** The songs are shown in their familiar-obscure pairs, with the obscure items in italics. The pair selected for the MQRTB is highlighted in red.

5.2.2 Phase Two: Pilot Testing of the MQRTB Procedure

Phase two involved testing the computer based MQRTB for task complexity and length, and to assess the suitability of the rating scales selected for use. On average, participants took 19.8 minutes to complete the MQRTB task (SD = 5.09, max = 29, min = 12).

This phase also found that the sound quality attributes being assessed were appropriate, and understood by the majority of participants. The task length was appropriate, with no participants requiring to listen to the full length of the song when rating the sound quality. Some commented on the variability in perceived loudness of the songs, and that the introductions of some songs were long (before the main body of the piece started). It was noted that for the first three scales (pleasantness, naturalness, and richness) many of the participants chose to leave the pointer at the default mid-point position.

Based on these observations the following changes were made to the MQRTB: (1) all songs were edited to between 2.5 – 3.5 minutes long, with the long introduction of 'Do you believe?' (the obscure country and western item) shortened; (2) all items were normalised to -16dB RMS; (3) the default starting position of the pointer for the first three scales was moved to the far left of the rating scale; (4) the minor scale divisions along the length of the rating scales were removed, as a true VAS does not gradate the scale in any way, and the author wished to align the format of these scales to that of previous research. An example of the changes made to the rating scales during the pilot testing is shown in Figure 5.6.

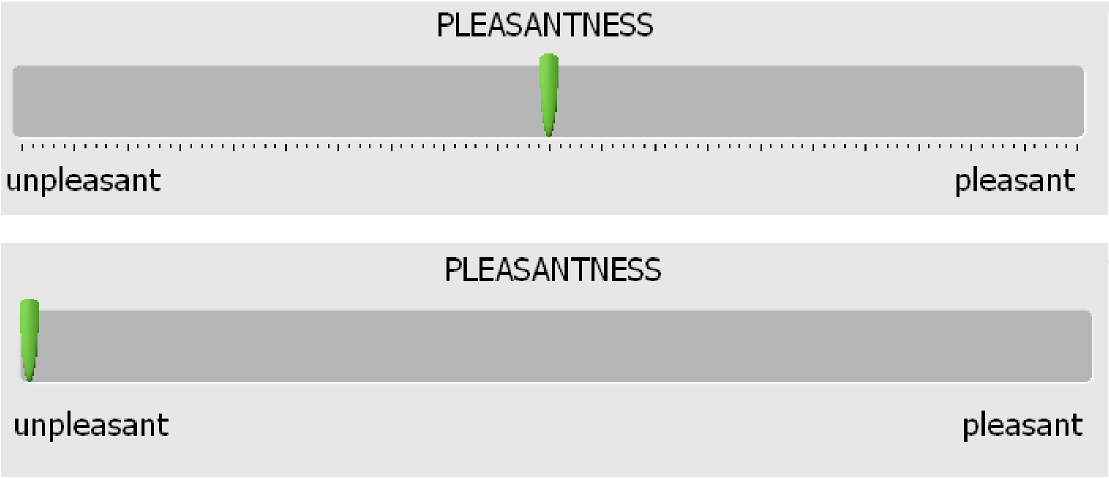

Figure 5.6: An example of the changes made to the MQRTB rating scales during the pilot testing (phase two).
The original scale is shown first, with the final scale underneath, showing the minor tick marks removed and default marker position shifted to the far left of the scale.

5.2.3 Phase Three: Pilot Testing of the FSP Versus HDCIS Comparison Study Procedure

Phase three consisted of pilot testing the complete session for the FSP versus HDCIS study, including both the MQRTB and speech perception testing. Feedback from participants indicated that task instructions were clear and correctly understood, with the total length of the testing session being 1-1.5 hours long. As this phase three did not give rise to any issues for the participants, no further changes to the MQRTB or methodology were made.

Chapter 6. Comparison of Music Quality Ratings for the FSP and HDCIS Processing Strategies

The chapter is separated into two sub-sections. Firstly the methods for the FSP versus HDCIS comparison study are presented (section 5.2), followed by the results of this study (section 6.2).

6.1 Methods for the FSP Versus HDCIS Comparison Study

6.1.1 Participants

This study involved five post-lingually deafened MED-EL CI recipients from NZ Australia. All participants were implanted with a Sonata$_{TI}^{100}$ or Pulsar$_{CI}^{100}$ implant, and used an OPUS 2 speech processor with the FSP speech processing strategy. Inclusion criteria for this study required that the participants; (1) be implanted for a minimum of six months, and not require re-programming for the nine week duration of the study; (2) were utilising at least one CSSS channel; (3) were physically able to travel to the test centres (Christchurch or Perth); (4) were not a MED-EL Duet user (i.e. utilising unilateral electric-acoustic stimulation); (5) had a good working knowledge of English; and (6) had no other major cognitive impairments which may affect their ability to carry out the tasks. Additional details of the participants included in the study are provided in Table 2.

Table 2: Participant details for the FSP versus HDCIS music quality study.

	Age	Sex	Implant Type	Number of FSP channels	Number of channels of stimulation	Side implanted	Time implanted (years, months)	Experience with FSP (years, months)	Length of deafness pre-implant (years)	Aetiology	Contralateral stimulation	Music Experience*
CI1	66	M	Pulsar	1	12	Right	3y 2m	2y	14	Ménière's Disease	None	2
CI2	44	F	Sonata	2	12	Left	1y	1y	30	Congenital, late onset	Cochlear Nucleus CI24 with 3G processor (Implanted 7 years)	3
CI3	69	F	Pulsar	1	12	Left	1y 9m	1y 9m	15	Mastoiditis	Hearing aid (BTE)	2
CI4	71	F	Sonata	1	7 (partial insertion)	Left	1y 5m	1y 5m	6-7	Combined genetic & ototoxicity	Hearing aid (BTE)	3
CI5	67	M	Pulsar	1	9 (partial insertion)	Right	2y 5m	1y 10m	30+	Noise exposure with possible genetic contribution	MED-EL Sonata with Opus 2 processor (Implanted 6 months)	1

* Music experience was determined from the responses to the music training and experience questionnaire (Appendix F).
1 = No formal music training or study; 2 = 5 or fewer years of formal music training or study; 3 = greater than 5 years of formal music training or study.

6.1.2 Equipment and Materials

Programming of the CI was carried out with the MED-EL MAESTRO® Programming Suite (Version 3.0.1). The MQRTB stimuli were presented via a Sony MHCGT22 home stereo system, in order to replicate the 'typical' home listening experience. The equipment used to present speech perception materials in the freefield differed between testing centres. The Christchurch centre used a Crown D-75 amplifier and JBL Ti 100 loudspeaker, while Perth used an Interacoustics AP70 amplifier and JBL LX-40 loudspeaker. Both the music and speech stimuli were presented from a Dell Vostro 1510 laptop computer.

The MQRTB

A detailed description of the MQRTB development, composition, and format is provided in Section 5.1.

Speech Perception Tests

The Consonant-Nucleus-Consonant (CNC) words test (Peterson & Lehiste, 1962), and the University of Melbourne CUNY-like sentence lists, which are an Australian recording of the City University of New York (CUNY) sentence test (Boothroyd, Hanin, & Hnath, 1985) were used. The CNC words test consists of 10 pre-recorded lists of 50 phonemically balanced mono-syllabic words, whereas the CUNY-like sentences test consists of 60 pre-recorded lists each with 12 sentences. Both speech tests used female speakers. For the CNC words, separate recordings of New Zealand and Australian speakers were used depending on the participant's location, whereas for the CUNY-like sentences, only an Australian speaker recording was available, therefore this was used for all participants. Six CUNY-like lists were excluded from the study, as they may have biased the results towards the Australian participants due to colloquial language used (e.g. sentences containing typically Australian words such as jumper and koala). To ensure that results were not biased to the NZ participants, the 5 CNC word lists used by the Southern Cochlear Implant Programme in their rehabilitation sessions were not used to test the participants in this study, therefore resulting in 5 possible lists to randomly select from.

Sound Level Measurements

Sound level measurements were carried out in Christchurch using a Solo Sonomèter 01dB sound level meter, and a Rion NA-61 sound level meter in Perth, both set on the fastest sampling rate (1 second).

6.1.3 Procedure

Ethical approval for this study was obtained from the Upper South B Health and Disabilities Ethics Committee (NZ), the University of Canterbury Human Ethics Committee, and the University of Western Australia Human Research Ethics Committee. All procedures were conducted in accordance with these approvals. Potential participants were sent an introductory letter, information sheet, consent form, and questionnaire by their respective CI centre.

Prior to testing, participants completed a music training and background questionnaire developed for this study (see Appendix F). This aimed to assess their formal training with music, and/or participation in music activities both now, and pre-CI. For statistical analysis, a rating of each participant from 1 to 3 was given depending on their level of musical experience (see Table 2). The participants were also asked to nominate and supply two favourite musical pieces on CD to be included in the test battery. The details of these favourite pieces are provided in Appendix G.

Testing was carried out at the University of Canterbury Speech and Hearing Clinic, or the Perth Lion Hearing Clinic (Implant Centre). All testing was undertaken in a sound treated room, with the participant positioned 1 metre from the speaker, at 0 degrees azimuth for all stimuli.

Testing for all participants consisted of three sessions. In session one the participant's everyday FSP strategy was copied and modified to a HDCIS strategy, by removing the CSSS channels. This was allocated to a redundant program position in the speech processor. The FSP strategy was not altered in any way. Following the creation of an HDCIS programme, the MQRTB was administered to provide baseline data with the participant acclimatised to their everyday FSP strategy. At the end of the session the participant was randomly, and blindly assigned either the FSP or HDCIS strategies (X1) to be used in everyday listening for three weeks. This processing strategy was placed in the redundant program slot used previously and the participant was instructed to use this as the default strategy until the next testing session.

In the second testing session, speech testing was carried out using X1, followed by a retest of the MQRTB. Following this, the participant was assigned the alternate processing strategy (X2) to use for the second phase of three weeks.

Session three started with speech testing using X2, followed by the MQRTB. At the conclusion of testing, the participants returned to use the original FSP program as set by their audiologist prior to the study.

MQRTB Testing:

To re-cap, the MQRTB consisted of 10 songs across 5 different categories and genres. An obscure and familiar piece for each of modern (pop/rock), classical, common (such as a national anthem or iconic melody), and country and western genres were supplemented with two pieces of the participant's favourite music.

Presentation levels of the music stimuli were at individually verified overall comfortable levels determined prior to testing, with the participant allowed to adjust the stereo volume via the remote control during the session.

For each item of the MQRTB, the participant used a touch screen to mark their ratings on the six scales when listening with one of the speech processing strategies. Once their six judgements had been made, the test administrator switched the participant's speech processor to the alternate processing strategy and repeated the song, with the participant now making their ratings for the second strategy. This process was repeated for the ten songs of the MQRTB. The position of the ratings, as placed on the touch screen by the participant, was converted to a number by the software for future data analysis. Presentation of the MQRTB song order was randomised, as was the speech processing strategy used when hearing an item the first time. The participants were not told which speech processing strategy they were listening with at any stage in the session.

Speech Perception Testing:

Speech testing was carried out in an auditory-alone condition (i.e. without visual cues), with stimuli presented at 65 dB(A) at the participant's speech processor microphone level, consistent with standard audiological clinical procedures. One randomly selected CUNY-like sentence list was presented in quiet and another with competing multi-talker babble at a SNR of +10 dB. The participant was required to repeat back what they heard. The number of words correctly repeated by the participant was totalled and a percent words-correct was calculated for each list. One randomly selected CNC word list was then presented in quiet, with the participant required to repeat back what they heard. A percent words-correct score and phonemes-correct score was calculated for the list.

6.2 Results for the Comparison of Music Quality Ratings with FSP and HDCIS

As there were only five participants, the ability to carry out group statistics and group comparisons are limited. Therefore it is more appropriate to consider each participant individually, as a case-study. Group analysis is also presented in order to show trends in the data which can later be compared to existing research. The results of speech perception testing and musical experience are also presented, however, again due to the small numbers of participants, statistical analysis is not appropriate. Hence the results section is organised as follows.

Data for each hypothesis is presented separately, with sub-headings for each research participant, followed by an overall group analysis. For the first two hypotheses, the data used was from the second and third testing sessions, whereas for the third and fourth hypotheses, the analysis includes the data obtained in the baseline session. For the first three VAS (pleasantness, naturalness and richness), the absolute values of the ratings are used, as the higher the value, the more preferable the rating. For the second three MPS (fullness, sharpness and roughness), which used the mid-point indicator "exactly as I want it to sound", the raw rating value is a representation of how far away from 'perfect' the sound is. That is, a higher value does not necessarily indicate a better result. Therefore the data shown has been transformed by taking the absolute value of the rating subtracted from five[3] (i.e. $|5 - rating|$). A larger value indicates a rating that is further away from the preferred sound, as a value of zero indicates 'exactly as I want it to sound'. An example of how the two different ratings were transformed is shown in Figure 6.1. The blue marker point has a raw value of 2, and is transformed to a value of 3 (i.e. 3 from the mid-

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[3] This value was used because the touchscreen program converted the marker positions to numerical values, with the extreme left = 0, the mid-point = 5, and the extreme right = 10. By subtracting 5 from the raw rating value, the values used in analysis were relative to the mid-point.

point). The green marker point has a raw value of 7, and is transformed to a value of 2 (i.e. 2 from the mid-point). This value does not indicate in which direction the rating is (i.e. to the left or right of the mid-point), however, this information is provided in each of the relevant figures.

Figure 6.1: **An example of how the MPS raw values were transformed.** The blue marker point has a raw value of 2, and is transformed to a value of 3 (i.e. 3 from the mid-point). The green marker point has a raw value of 7, and is transformed to a value of 2 (i.e. 2 from the mid-point).

In addition to presenting the data for the six rating scales, the ratings have been combined into two further categories; the 'averaged-VAS', which represents an average of the first three scales (pleasantness, naturalness, and richness), and the 'averaged-MPS', which represents the average of the second three scales (fullness, sharpness, and roughness). These are used to gain an overall picture of the ratings, as it is evident that a positive or negative rating on a single scale may not necessarily imply a preference for a strategy.

All statistical analysis for this research was carried out using SPSS 17.0 software (SPSS Inc., 2008). All parametric and non-parametric tests were two tailed, with a significance value of $p \leq 0.05$ being adopted (unless otherwise stated).

6.2.1 Hypotheses One – Familiarity with Processing Strategy

Familiarity with either FSP or HDCIS will affect the quality ratings of CI recipients, with the processing strategy the participants are acclimatised to being preferred in music quality ratings, To recap, after the baseline session, participants were randomly allocated either FSP or HDCIS to use as their everyday strategy for a period of three weeks. This was in order for the participant to acclimatise to the strategy before their next session.

This hypothesis aims to answer whether there is a difference in ratings, depending on which strategy the participant is acclimatised to. The results of this will impact on how the later hypotheses are analysed and interpreted. If no acclimatisation effect is found, sessions can be combined regardless of which processing strategy the participant is acclimatised to. Conversely, if it is shown that there is an acclimatisation effect, the session data will require separate analysis.

For the analysis of acclimatisation, ratings from the averaged-VAS and averaged-MPS were used to assess for an acclimatisation effect, as acclimatisation for one scale-only is not necessarily indicative of an overall acclimatisation effect. That is, it was felt that acclimatisation to a strategy would be better represented by considering the VAS and MPS collectively.

To enable comparisons between the testing sessions, the relative difference between the FSP and HDCIS ratings for each scale within a single session was calculated to obtain a Session Strategy Difference (SSD) score. For example, if the participant rated the pleasantness as 7.5 using FSP and 5.2 using HDCIS, the SSD would be calculated as 2.3. The magnitude of the SSD can be used as an indicator of the ability to differentiate between processing strategies. That is, a larger SSD suggests a greater perceptual difference between FSP and HDCIS. A non-parametric Wilcoxon signed ranks test ($p \leq 0.05$) was then used to compare the SSD values obtained for the two acclimatisation conditions, with a significant result suggesting an acclimatisation effect. For example, if, when acclimatised to FSP, a rating of 9 was given when listening with FSP and 5 for HDCIS, the SSD would be 4. If, when acclimatised to HDCIS, the FSP rating was 7 and the HDCIS rating was 6, the SSD is now 1. As these show a larger difference between the FSP and HDCIS ratings when acclimatised to FSP, it suggests a greater preference for FSP, than when acclimatised to HDCIS.

When examining the SSD values, it is important to take note of the +/- sign. For the VAS, a positive value shows a FSP preference, and a negative value indicates a HDCIS preference, since a larger rating indicates a more preferable sound. For the MPS, a positive value shows a HDCIS preference, and a negative value indicates a FSP preference, since a larger rating indicates a greater deviation from the 'perfect' sound, and hence decreased preference. This is represented in Tables 3 - 8 by the different font colours, with red values showing a FSP preference, and blue values a HDCIS preference.

Therefore an acclimatisation effect can be shown in two ways. Firstly, a significant difference between the SSDs for each acclimatisation condition indicates an effect of acclimatisation, and secondly, processing strategy preferences (shown by the negative or positive SSD value) after having accounted for which strategy the participant was acclimatised to (e.g. when acclimatised to FSP, the subject prefers FSP, and when acclimatised to HDCIS the subject prefers HDCIS).

Participant CI1

Table 3 shows participant CI1's mean SSDs for all scales when acclimatised to FSP and HDCIS, as well as the results of the Wilcoxon test comparing the SSDs. It shows that for CI1 there are no statistically significant differences between the averaged SSDs on any scales, regardless of whether he was acclimatised to FSP or HDCIS. However, the sign of the SSD values suggests some degree of acclimatisation, as it appears that when acclimatised to FSP the subject prefers FSP, and when acclimatised to HDCIS, they prefer HDCIS (as indicated by the blue and red text). This trend though, was not statistically significant, and therefore it has been concluded that there is no acclimatisation effect for this subject.

Table 3: **Mean SSDs for CI1 with Wilcoxon test results comparing the SSD values.** Each rating scale is shown, along with the averaged-VAS and averaged-MPS, when acclimatised to FSP and HDCIS. Wilcoxon test results compare the mean SSD values obtained when acclimatised to each strategy.

	Mean SSD (SD), acclimatised to FSP	Mean SSD (SD), acclimatised to HDCIS	Wilcoxon test comparison of mean SSDs	
			Z	p
Pleasantness	0.29 (0.75)	-0.06 (0.81)	-1.683	0.092
Naturalness	0.57 (1.25)	-0.13 (1.01)	-1.478	0.139
Richness	0.45 (1.10)	-0.12 (0.46)	-0.968	0.333
Averaged-VAS	0.44 (0.96)	-0.11 (0.62)	-1.478	0.139
Fullness	-0.06 (0.59)	0.13 (0.42)	-0.770	0.441
Sharpness	-0.05 (0.60)	0.00 (0.48)	-0.051	0.959
Roughness	-0.07 (0.46)	-0.06 (0.50)	-0.296	0.767
Averaged-MPS	-0.06 (0.49)	0.03 (0.43)	-0.459	0.646

Red text indicates a preference to FSP, whereas blue text shows a preference to HDCIS.

Participant CI2

Table 4 shows participant CI2's mean SSDs for all scales when acclimatised to FSP and HDCIS, as well as the results of the Wilcoxon test comparing the SSDs. Although the participant preferred FSP regardless of which strategy she was acclimatised to, the Wilcoxon test showed an acclimatisation effect for all of the VAS (pleasantness, naturalness, richness) and the sharpness scale, as the SSD was significantly smaller when acclimatised to HDCIS than when acclimatised to FSP. Figure 6.2 illustrates this by showing the absolute ratings of the three VAS when acclimatised to FSP and HDCIS. It is clear that the FSP ratings, when acclimatised to FSP, are higher than all other conditions; even when acclimatised to HDCIS, FSP was still rated higher. For this participant, the acclimatisation effect is evident in that the difference between the ratings (i.e. SSD) is significantly greater when acclimatised to FSP than when acclimatised to HDCIS.

Table 4: **Mean SSDs for CI2 with Wilcoxon test results comparing the SSD values.** Each rating scale is shown, along with the averaged-VAS and averaged-MPS, when acclimatised to FSP and HDCIS. Wilcoxon test results compare the mean SSD values obtained when acclimatised to each strategy.

	Mean SSD (SD), acclimatised to FSP	Mean SSD (SD), acclimatised to HDCIS	Wilcoxon test comparison of mean SSDs	
			Z	p
Pleasantness	4.03 (2.25)	0.84 (1.65)	-2.803	0.005*
Naturalness	4.01 (2.35)	0.66 (1.80)	-2.803	0.005*
Richness	4.36 (2.67)	1.04 (2.02)	-2.497	0.013*
Averaged-VAS	4.13 (2.32)	0.85 (1.81)	-2.803	0.005*
Fullness	-1.99 (1.35)	-1.30 (1.80)	-1.120	0.263
Sharpness	-1.97 (1.37)	-0.69 (1.46)	-2.192	0.028*
Roughness	-1.74 (1.35)	-0.73 (1.60)	-1.836	0.066
Averaged-MPS	-1.90 (1.30)	-0.91 (1.46)	-1.955	0.051

* indicates those values which are significant (p ≤ 0.05). Red text indicates a preference to FSP, whereas blue text shows a preference to HDCIS.

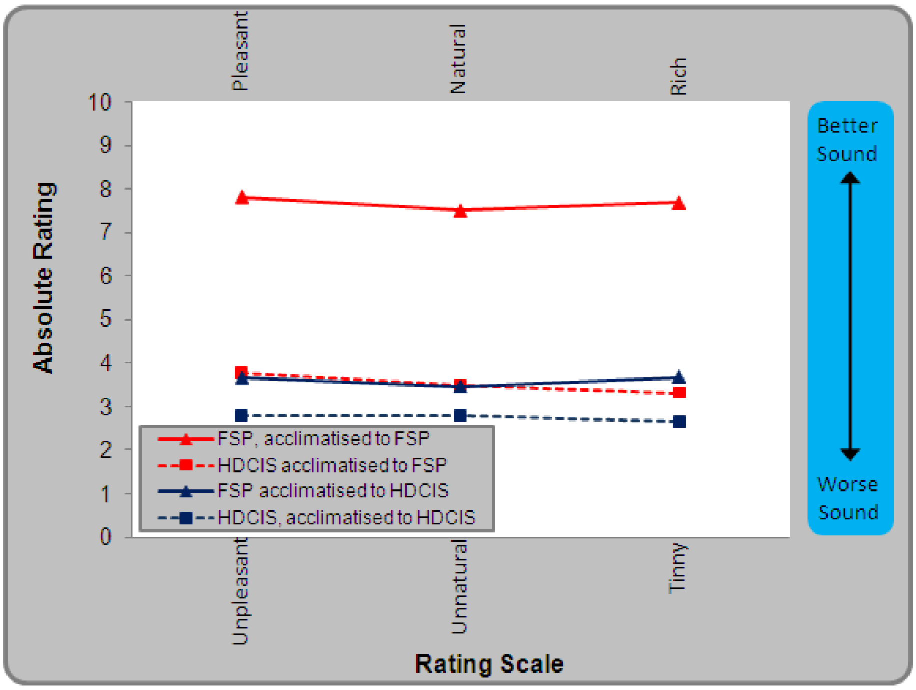

Figure 6.2: **Average ratings for participant CI2 on the VAS for FSP and HDCIS, while acclimatised to each strategy.**

Participant CI3

Table 5 shows participant CI3's mean SSDs for all scales when acclimatised to FSP and HDCIS, as well as the results of the Wilcoxon test comparing the SSDs. It shows that for CI3 there were no statistically significant differences between the averaged

SSDs on any scales, regardless of whether the participant was acclimatised to FSP or HDCIS. The SSD values actually suggest a reverse acclimatisation effect; when acclimatised to FSP, the participant showed a preference to HDCIS whereas when acclimatised to HDCIS they preferred FSP, however, the effect is not at the level of statistical significance. Therefore, this data showed that there is no acclimatisation effect for this participant.

Table 5: **Mean SSDs for CI3 with Wilcoxon test results comparing the SSD values.** Each rating scale is shown, along with the averaged-VAS and averaged-MPS, when acclimatised to FSP and HDCIS. Wilcoxon test results compare the mean SSD values obtained when acclimatised to each strategy.

	Mean SSD (SD), acclimatised to FSP	Mean SSD (SD), acclimatised to HDCIS	Wilcoxon test comparison of mean SSDs	
			Z	p
Pleasantness	-0.48 (3.78)	0.03 (2.59)	-0.459	0.646
Naturalness	-0.46 (3.82)	0.13 (1.77)	-0.561	0.575
Richness	-1.12 (3.23)	-0.11 (2.71)	-0.866	0.386
Averaged-VAS	-0.69 (3.50)	0.02 (1.94)	-0.764	0.445
Fullness	0.27 (0.84)	-0.27 (0.61)	-1.274	0.203
Sharpness	0.00 (1.10)	-0.35 (1.09)	-0.663	0.508
Roughness	0.36 (1.58)	-0.18 (1.37)	-1.376	0.169
Averaged-MPS	0.21 (1.00)	-0.27 (0.94)	-1.682	0.093

Red text indicates a preference to FSP, whereas blue text shows a preference to HDCIS.

Participant CI4

Table 6 shows participant CI4's mean SSDs for all scales when acclimatised to FSP and HDCIS, as well as the results of the Wilcoxon test comparing the SSDs. The roughness scale has not been included as the participant chose not to rate on this scale; she felt she did not have an understanding of the smooth-rough percept. Although the participant preferred HDCIS regardless of which strategy she was acclimatised to, the Wilcoxon test showed an acclimatisation effect for all of the rated scales, as the SSDs were significantly smaller when acclimatised to FSP than when acclimatised to HDCIS.

Table 6: **Mean SSDs for CI4 with Wilcoxon test results comparing the SSD values.** Each rating scale (except roughness) is shown, along with the averaged-VAS and averaged-MPS, when acclimatised to FSP and HDCIS. Wilcoxon test results compare the mean SSD values obtained when acclimatised to each strategy.

	Mean SSD (SD), acclimatised to FSP	Mean SSD (SD), acclimatised to HDCIS	Wilcoxon test comparison of mean SSDs	
			Z	p
Pleasantness	-0.11 (1.08)	-1.36 (0.42)	-2.497	0.013*
Naturalness	-0.06 (0.87)	-1.39 (0.45)	-2.599	0.009*
Richness	-0.12 (1.13)	-1.29 (0.48)	-2.293	0.022*
Averaged-VAS	-0.10 (1.02)	-1.35 (0.41)	-2.497	0.013*
Fullness	0.26 (1.13)	1.41 (0.41)	-2.395	0.017*
Sharpness	0.27 (1.00)	1.36 (0.47)	-2.191	0.028*
Roughness	▨	▨	▨	▨
Averaged-MPS	0.18 (0.71)	0.92 (0.29)	-2.395	0.017*

* indicates those values which are significant (p ≤ 0.05). Red text indicates a preference to FSP, whereas blue text shows a preference to HDCIS.

Participant CI5

Table 7 shows participant CI5's mean SSDs for all scales when acclimatised to FSP and HDCIS, as well as the results of the Wilcoxon test comparing the SSDs. When examining the data there is some conflicting information. For the VAS (pleasantness, naturalness, richness), there was no significant difference between mean SSDs, consistent with there being no acclimatisation effect. For the VAS, the participant consistently preferred HDCIS regardless of which processing strategy they were acclimatised to. In contrast, for the MPS of fullness and sharpness, as well as the averaged-MPS, there was a significant difference between ratings, with a larger SSD when acclimatised to FSP. These results suggest that for the MPS there was an acclimatisation effect. It is of interest to note that the SSD signs showed that for the VAS this subject preferred HDCIS, however, for the MPS they preferred FSP, regardless of the strategy they were acclimatised to. Therefore for participant CI5, acclimatisation appears to have some effect on music quality ratings, however, only for the MPS.

Table 7: **Mean SSDs for CI5 with Wilcoxon test results comparing the SSD values.** Each rating scale is shown, along with the averaged-VAS and averaged-MPS, when acclimatised to FSP and HDCIS. Wilcoxon test results compare the mean SSD values obtained when acclimatised to each strategy.

	Mean SSD (SD), acclimatised to FSP	Mean SSD (SD), acclimatised to HDCIS	Wilcoxon test comparison of mean SSDs	
			Z	p
Pleasantness	-0.93 (0.83)	-0.71 (0.98)	-0.764	0.445
Naturalness	-1.14 (0.74)	-0.84 (0.73)	-1.172	0.241
Richness	-0.72 (0.82)	-0.96 (0.75)	-0.459	0.646
Averaged-VAS	-0.93 (0.76)	-0.84 (0.78)	-0.459	0.646
Fullness	-1.14 (1.06)	-0.20 (0.51)	-2.293	0.022*
Sharpness	-0.95 (1.03)	-0.06 (0.18)	-2.201	0.028*
Roughness	-0.61 (0.61)	-0.02 (0.74)	-1.886	0.059
Averaged-MPS	-0.90 (0.85)	-0.09 (0.44)	-2.497	0.013*

* indicates those values which are significant (p ≤ 0.05). Red text indicates a preference to FSP, whereas blue text shows a preference to HDCIS.

Average data across all five participants.

To obtain the group data shown in Table 8, an average of the original FSP and HDCIS values from each participant was calculated for each scale. From this, the average HDCIS value was subtracted from the average FSP value to calculate the group average SSD. The data shows mixed results. The SSD values for each VAS (pleasantness, naturalness, richness) and the averaged-VAS are significantly larger when acclimatised to FSP than when acclimatised to HDCIS, which is consistent with an acclimatisation effect. That is, when acclimatised to FSP the group provides ratings that are suggestive of an enhanced ability to tell the difference between the sound of FSP and HDCIS, as the mean FSP SSD is larger than the HDCIS SSD. Figure 6.3 illustrates this by showing the averaged ratings for each VAS, and each strategy; the FSP rating was higher when acclimatised to FSP than when acclimatised to HDCIS. For the MPS (fullness, sharpness, roughness), the Wilcoxon test showed significant differences between the SSD values for the sharpness and averaged-MPS. There was a clear FSP preference on all rating scales when acclimatised to FSP but the direction of preference was mixed when acclimatised to HDCIS. Overall it appears that for the averaged group data there was a significant acclimatisation effect for most of the rating scales, the effect being larger for the VAS than MPS, and that acclimatisation to FSP resulted in higher SSD values.

Table 8: **Mean SSDs for the averaged group data with Wilcoxon test results comparing the SSD values.**
Each rating scale is shown, along with the averaged-VAS and averaged-MPS, when acclimatised to FSP and HDCIS. Wilcoxon test results compare the mean SSD values obtained when acclimatised to each strategy.

	Mean SSD (SD), acclimatised to FSP	Mean SSD (SD), acclimatised to HDCIS	Wilcoxon test comparison of mean SSDs	
			Z	p
Pleasantness	0.56 (1.08)	-0.25 (0.65)	-1.988	0.047*
Naturalness	0.59 (1.04)	-0.32 (0.49)	-2.293	0.022*
Richness	0.57 (0.82)	-0.29 (0.61)	-2.293	0.022*
Averaged-VAS	0.57 (0.95)	-0.29 (0.50)	-2.293	0.022*
Fullness	-0.53 (0.50)	-0.05 (0.49)	-1.886	0.059
Sharpness	-0.54 (0.51)	0.05 (0.44)	-2.803	0.005*
Roughness	-0.52 (0.58)	-0.25 (0.57)	-1.172	0.241
Averaged-MPS	-0.53 (0.48)	-0.08 (0.44)	-2.599	0.009*

* indicates those values which are significant ($p \leq 0.05$). Red text indicates a preference to FSP, whereas blue text shows a preference to HDCIS.

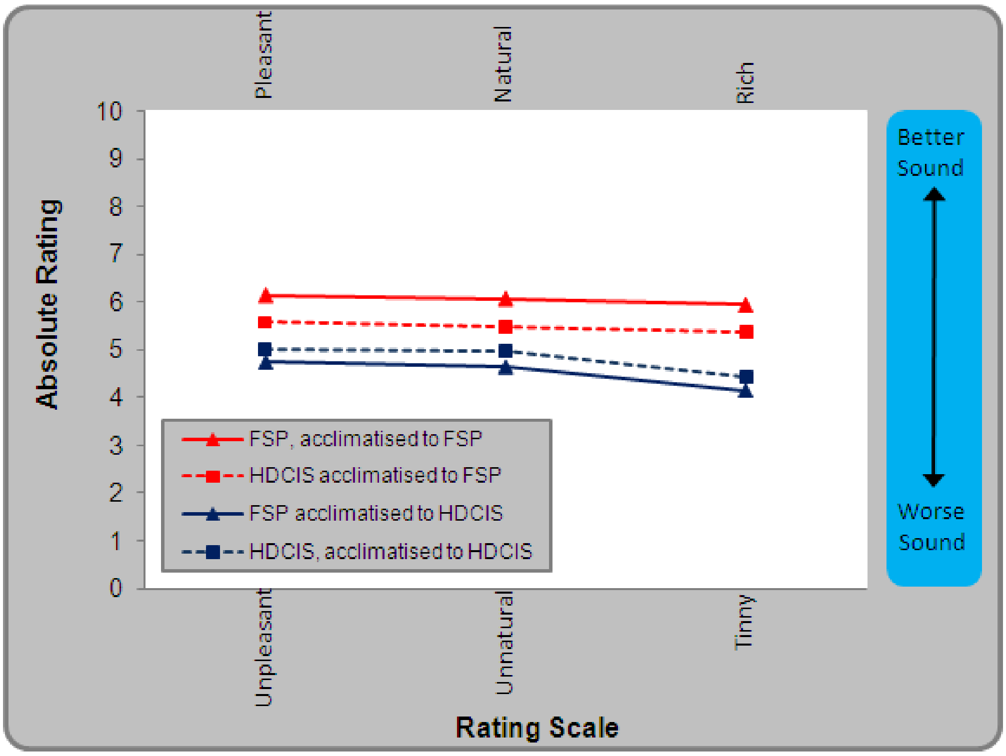

Figure 6.3: **Average ratings for the group on the VAS when listening to FSP and HDCIS, while acclimatised to FSP and HDCIS.**

6.2.2 Hypotheses Two – Strategy Preference

CI recipients will prefer the sound of FSP over HDCIS on the rating scales of pleasantness, naturalness, richness, fullness, sharpness, and roughness,

The acclimatisation data described in the previous section suggested the presence of some degree of acclimatisation for a few of the individuals and the averaged data across all participants. Therefore the data comparing the FSP and HDCIS ratings in Tables 9 - 14 have been separated into one data set where the strategy the participant was acclimatised to is kept separate, and another where the ratings were combined without accounting for which strategy participants were acclimatised to. For each participant, if there was an acclimatisation effect, (as indicated in Section 6.2.2) the subsequent analysis will concentrate on the separated data set. If there was no acclimatisation effect shown, the analysis will concentrate on the combined data, as there was no need to account for which strategy the participant was acclimatised to when providing the rating.

To analyse the data, non-parametric Wilcoxon signed ranks tests were used to compare the mean FSP and HDCIS ratings. A significant difference ($p \leq 0.05$) would indicate that one processing strategy is preferred over the other.

For Tables 9 - 13, when examining the data, the mean FSP and HDCIS ratings for the first three VAS (pleasantness, naturalness, richness) are absolute values with a possible maximum value of 10. For the three MPS, the magnitude of the rating reflects how far away it was from the mid-point which was labelled “exactly as I want it to sound”. That is, instead of reporting the raw rating provided, the original score has been transformed by taking the absolute value of the original rating subtracted from five (i.e. $|5-rating|$). Therefore, for the MPS, a larger absolute value (i.e. ignoring the +/- sign) indicates a rating that is further away from the preferred sound (i.e. a worse rating). A value of zero indicates that the sound was exactly how the participant wanted it to sound. The broken horizontal line in Tables 9 - 14 indicates where the data magnitude is interpreted differently, as described above. To show the direction of the rating on the MPS (either to the right or left of the mid-point), Figures 6.4 - 6.15 show the un-transformed ratings provided by the participants.

Participant CI1

As reported in Section 6.2.2 there was no acclimatisation effect for this participant, hence the combined data in Table 9 will be referred to. However, irrespective of which data is considered, there were no significant differences between ratings made while using either FSP or HDCIS for any rating scale. This indicates that participant CI1 does not rate one strategy significantly better than the other. As can be seen in Figures 6.4 and 6.5, there was little difference between the FSP and HDCIS ratings. For the MPS, the mean ratings never deviated beyond the middle 20% of the scale, with the fullness and sharpness scales being to the left of the mid-point, suggesting that the sound was rated as emptier and duller than the participant would like it to sound. The mean rating for the roughness scale was to the right of the mid-point, indicating that the sound was rougher than the participant wanted it to sound.

Table 9: **Mean ratings when listening to FSP and HDCIS for CI1, with Wilcoxon test results.**
Average ratings for all six rating scales, and the averaged-VAS and averaged-MPS are shown, when the acclimatisation strategy is combined. Because no effect of acclimatisation was measured, the combined acclimatisation data is discussed.

	Acclimatised to											
	FSP				**HDCIS**				**Combined data**			
	Mean (SD) FSP	**Mean (SD) HDCIS**	**Wilcoxon test† Z**	**p**	**Mean (SD) FSP**	**Mean (SD) HDCIS**	**Wilcoxon test† Z**	**p**	**Mean (SD) FSP**	**Mean (SD) HDCIS**	**Wilcoxon test† Z**	**p**
Pleasantness	8.46 (0.72)	8.17 (0.74)	-1.070	0.285	8.15 (0.75)	8.22 (1.10)	-0.747	0.455	8.31 (0.73)	8.19 (0.91)	-1.172	0.241
Naturalness	8.37 (0.78)	7.80 (1.03)	-1.172	0.241	8.04 (0.79)	8.17 (1.24)	-0.459	0.646	8.21 (0.78)	7.98 (1.13)	-0.560	0.575
Richness	8.25 (0.70)	7.80 (0.96)	-1.172	0.241	4.93 (0.43)	5.05 (0.31)	-0.867	0.386	6.59 (1.79)	6.43 (1.57)	-0.429	0.668
Averaged-VAS	8.36 (0.72)	7.92 (0.84)	-1.274	0.203	7.04 (0.50)	7.15 (0.76)	-0.561	0.575	7.70 (0.91)	7.53 (0.88)	-0.672	0.502
Fullness	0.32 (0.36)	0.39 (0.42)	-0.280	0.779	0.38 (0.30)	0.24 (0.36)	-0.840	0.401	0.35 (0.32)	0.32 (0.39)	-0.181	0.856
Sharpness	0.42 (0.50)	0.47 (0.32)	-0.178	0.859	0.37 (0.32)	0.37 (0.42)	-0.280	0.779	0.39 (0.41)	0.42 (0.37)	-0.331	0.740
Roughness	0.35 (0.44)	0.42 (0.40)	-0.423	0.672	0.23 (0.28)	0.29 (0.42)	-0.140	0.889	0.29 (0.36)	0.36 (0.40)	-0.483	0.629
Averaged-MPS	0.36 (0.31)	0.43 (0.34)	-0.415	0.678	0.32 (0.27)	0.30 (0.36)	-0.051	0.959	0.34 (0.28)	0.36 (0.35)	-0.282	0.778

†The Wilcoxon test compared the mean FSP and HDCIS ratings for each rating scale and the averaged-VAS and averaged-MPS.

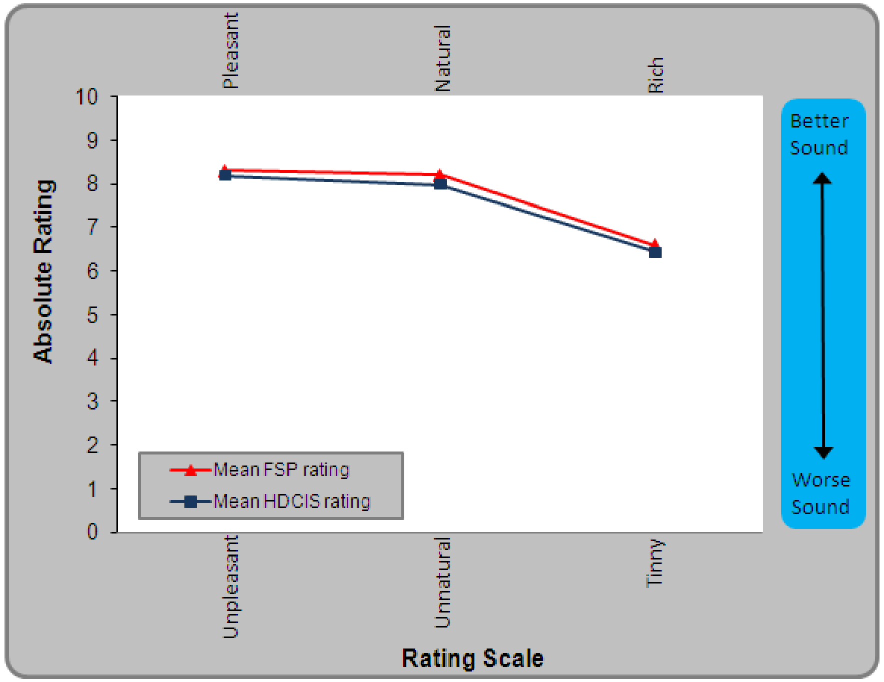

Figure 6.4: **The absolute ratings on the VAS for participant CI1.**
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

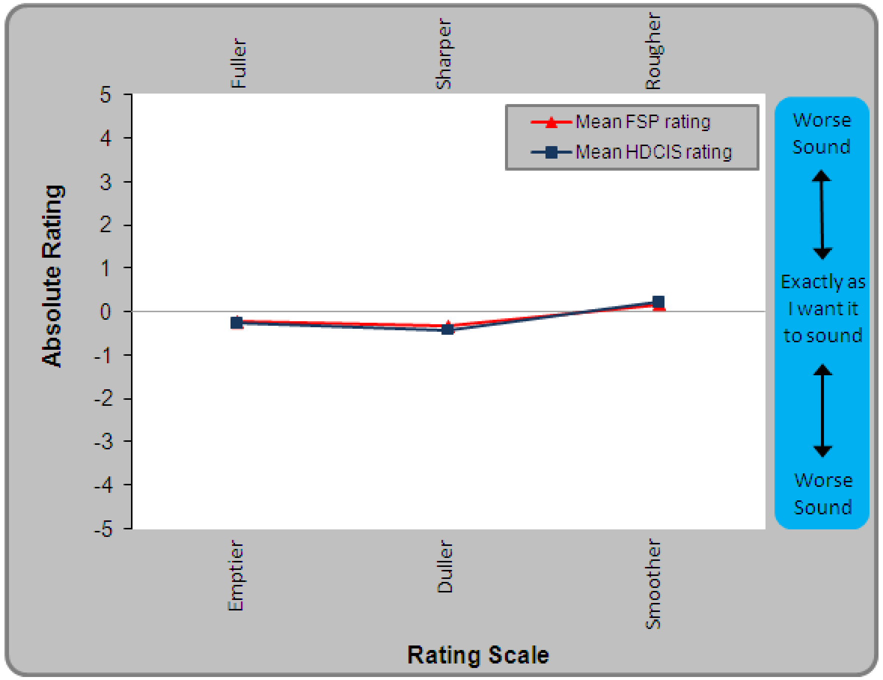

Figure 6.5: **The absolute ratings on the MPS for participant CI1.**
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

Participant CI2

As there was a significant acclimatisation effect for this participant as reported in Section 6.2.2, the separated 'acclimatised to FSP/HDCIS' data will be considered in Table 10. When acclimatised to FSP, the participant provided significantly higher ratings for the FSP strategy than HDCIS, for all of the individual rating scales, as well as the averaged-VAS and averaged-MPS. This can be seen in the higher mean values for the pleasantness, naturalness and richness scales, and with values closer to zero (i.e. 'exactly as I want it to sound') for the fullness, sharpness and roughness scales. Even when acclimatised to HDCIS, this participant still rated FSP as significantly better than HDCIS. When acclimatised to HDCIS, the trend was for the participant to place the ratings for both strategies closer together, suggesting that there was less perceived difference between the strategies, as discussed in Section 6.2.2. Figures 6.6 and 6.7 provide a comparison of the FSP and HDCIS ratings for the VAS and MPS respectively. They show that when acclimatised to FSP, the significant difference discussed in section 6.2.2 is due to a higher FSP rating (Figure 6.6). The figures also show that regardless of which strategy the participant was acclimatised to, she still rated FSP higher than HDCIS (Figure 6.6) and closer to what she wanted it to sound like (Figure 6.7). That is, the participant rated FSP more pleasant, natural and rich when compared to the HDCIS ratings. Furthermore, the MPS ratings for FSP were always closer to the mid-point than the HDCIS ratings, indicating that HDCIS was emptier, sharper and rougher than FSP.

Table 10: Ratings when listening to FSP and HDCIS for CI2, with Wilcoxon test results.
Average ratings for all six rating scales, and the averaged-VAS and averaged-MPS are shown, when acclimatised to each processing strategy. Because an effect of acclimatisation was measured, the separate acclimatised to FSP and HDCIS data is discussed.

	Acclimatised to											
	FSP				HDCIS				Combined data			
	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test† Z	p	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test† Z	p	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test† Z	p
Pleasantness	7.81 (1.30)	3.79 (3.06)	-2.803	0.005*	3.65 (0.78)	2.80 (1.14)	-3.248	0.001*	5.73 (2.38)	3.30 (2.30)	-2.803	0.005*
Naturalness	7.51 (1.96)	3.50 (2.98)	-2.803	0.005*	3.45 (0.59)	2.79 (1.38)	-1.070	0.285	5.48 (2.51)	3.15 (2.29)	-3.099	0.002*
Richness	7.68 (1.88)	3.32 (3.22)	-2.701	0.007*	3.68 (0.74)	2.64 (1.37)	-1.478	0.139	5.68 (2.48)	2.98 (2.44)	-3.211	0.001*
Averaged-VAS	7.67 (1.67)	3.53 (3.04)	-2.803	0.005*	3.59 (0.64)	2.75 (1.28)	-1.376	0.169	5.63 (2.43)	3.14 (2.31)	-3.248	0.001*
Fullness	0.25 (0.52)	2.24 (1.36)	-2.521	0.012*	0.42 (0.88)	1.72 (1.59)	-1.690	0.091	0.33 (0.71)	1.98 (1.47)	-2.953	0.003*
Sharpness	0.25 (0.42)	2.21 (1.35)	-2.524	0.012*	0.81 (1.03)	1.50 (1.16)	-1.260	0.208	0.53 (0.82)	1.86 (1.28)	-2.844	0.004*
Roughness	0.35 (0.64)	2.08 (1.27)	-2.521	0.012*	0.72 (0.86)	1.45 (1.06)	-1.007	0.314	0.53 (0.76)	1.77 (1.19)	-2.628	0.009*
Averaged-MPS	0.28 (0.46)	2.18 (1.31)	-2.521	0.012*	0.65 (0.81)	1.56 (1.14)	-1.599	0.110	0.46 (0.67)	1.87 (1.23)	-3.006	0.003*

* indicates those values which are significant ($p \leq 0.05$).
†The Wilcoxon test compared the mean FSP and HDCIS ratings for each rating scale and the averaged-VAS and averaged-MPS.

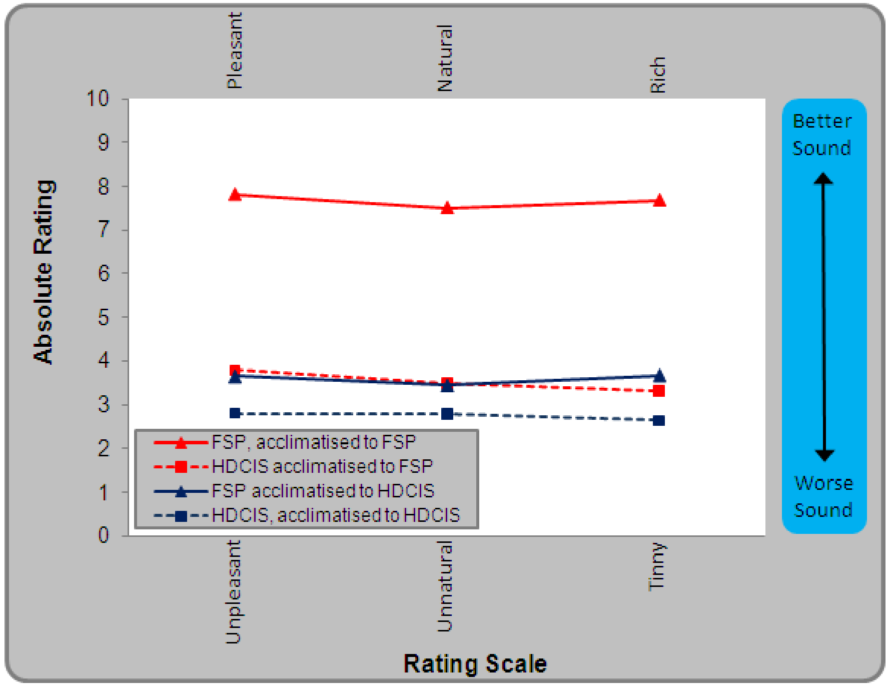

Figure 6.6: **The absolute ratings on the VAS for participant CI2.**
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

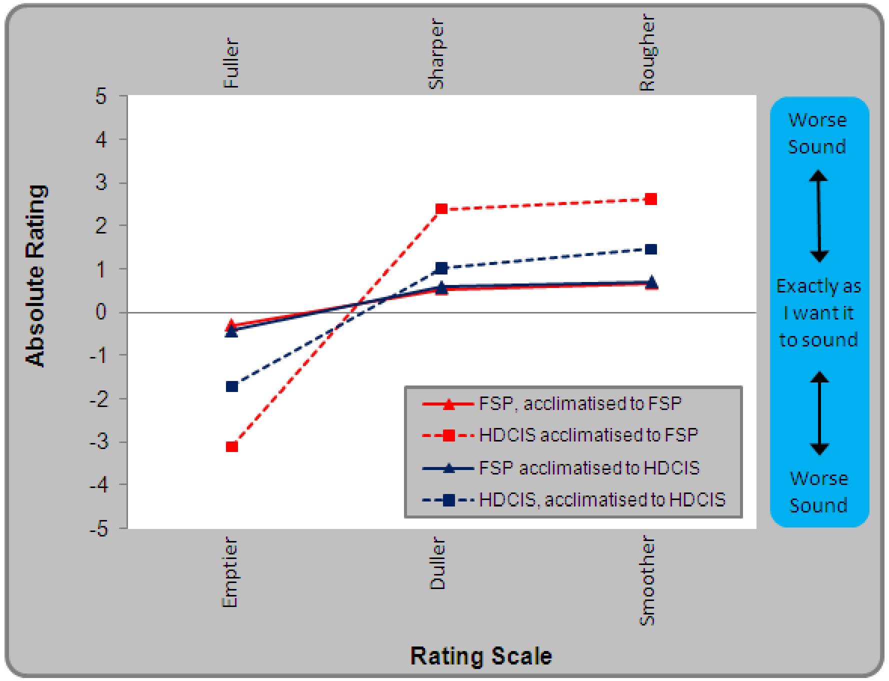

Figure 6.7: **The absolute ratings on the MPS for participant CI2.**
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

Participant CI3

As reported in Section 6.2.2 there was no acclimatisation effect for this participant, hence the combined data in Table 11 will be referred to. However, irrespective of which data is considered, there were no significant differences between ratings made while using either FSP or HDCIS for any rating scale. This indicates that participant CI3 did not rate one strategy significantly higher in quality than the other. As can be seen in Figures 6.8 and 6.9 there was little difference between the FSP and HDCIS ratings. For the MPS, the mean ratings never deviated beyond the middle 25% of the scale, (Figure 6.9) and the average rating was always fuller, sharper and smoother than what the participant wanted it to sound like, irrespective of which processing strategy she was acclimatised to.

Table 11: Ratings when listening to FSP and HDCIS for CI3, with Wilcoxon test results.
Average ratings for all six rating scales, and the averaged-VAS and averaged-MPS are shown, when the acclimatisation strategy is combined. Because no effect of acclimatisation was measured, the combined acclimatisation data is discussed.

	Acclimatised to								Combined data			
	FSP				HDCIS							
	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test†		Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test†		Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test†	
			Z	p			Z	p			Z	p
Pleasantness	4.83 (2.63)	5.31 (3.20)	-0.459	0.646	4.15 (1.76)	4.12 (1.45)	-0.336	0.737	4.49 (2.20)	4.72 (2.49)	-0.255	0.799
Naturalness	4.80 (2.65)	5.26 (3.27)	-0.255	0.799	3.93 (1.21)	3.80 (1.21)	-0.255	0.799	4.36 (2.05)	4.53 (2.51)	-0.037	0.970
Richness	3.96 (2.64)	5.08 (3.22)	-0.866	0.386	4.31 (1.84)	4.42 (1.51)	-0.357	0.721	4.13 (2.22)	4.75 (2.47)	-0.859	0.391
Averaged-VAS	4.53 (2.46)	5.22 (3.19)	-0.663	0.508	4.13 (1.42)	4.11 (0.99)	-0.357	0.721	4.33 (1.96)	4.66 (2.37)	-0.485	0.627
Fullness	1.03 (0.85)	0.76 (0.87)	-1.122	0.262	0.68 (0.54)	0.96 (0.73)	-1.362	0.173	0.86 (0.71)	0.86 (0.79)	-0.121	0.904
Sharpness	1.06 (0.81)	1.05 (0.90)	-0.255	0.799	0.69 (0.58)	1.05 (0.76)	-0.968	0.333	0.88 (0.71)	1.05 (0.81)	-0.597	0.550
Roughness	1.58 (1.30)	1.22 (1.34)	-0.663	0.508	1.06 (1.00)	1.24 (1.12)	-0.459	0.646	1.32 (1.16)	1.23 (1.20)	-0.336	0.737
Averaged-MPS	1.22 (0.93)	1.01 (0.90)	-0.561	0.575	0.81 (0.66)	1.08 (0.78)	-0.764	0.445	1.02 (0.81)	1.05 (0.82)	-0.075	0.940

†The Wilcoxon test compared the mean FSP and HDCIS ratings for each rating scale and the averaged-VAS and averaged-MPS.

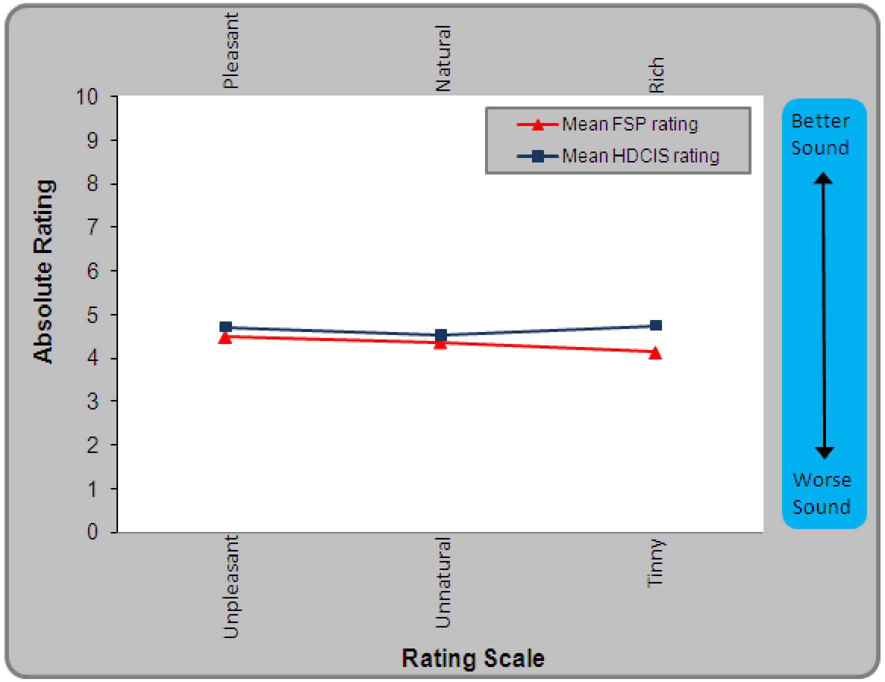

Figure 6.8: **The absolute ratings on the VAS for participant CI3.**
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

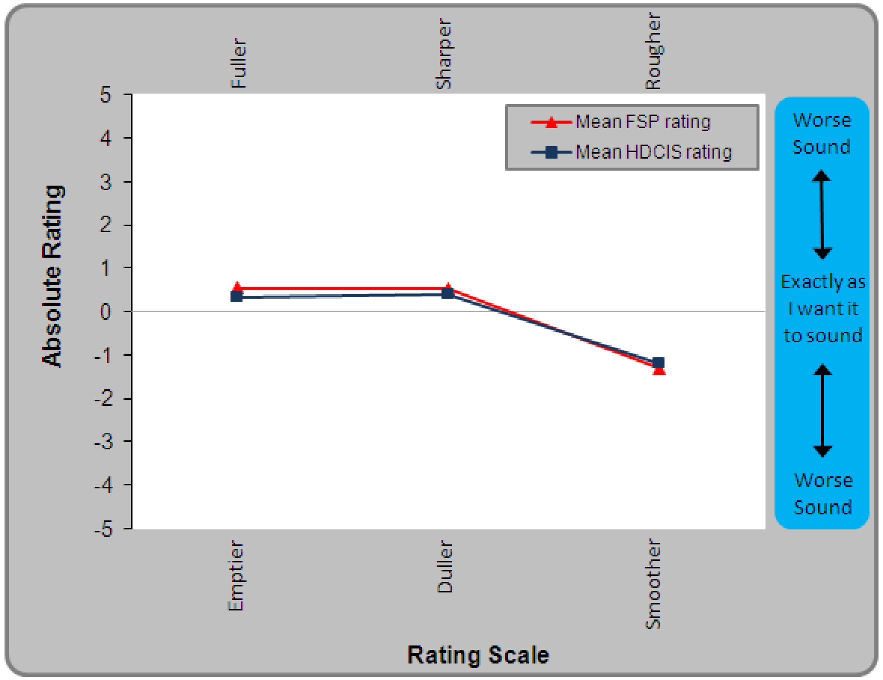

Figure 6.9: **The absolute ratings on the MPS for participant CI3.**
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

Participant CI4

As there was a significant acclimatisation effect for this participant reported in Section 6.2.2, the separated 'acclimatised to FSP/HDCIS' data will be referred to in Table 12. When acclimatised to HDCIS, the participant provided significantly higher ratings for the HDCIS strategy on all of the individual rating scales[4], as well as the averaged-VAS and averaged-MPS. This can be seen in the higher mean values for the pleasantness, naturalness and richness scales, and with values closer to zero (i.e. 'exactly as I want it to sound') for the fullness and sharpness scales. The mean values are consistently low for all scales (compared to the other participants); however, HDCIS is consistently rated higher than FSP. Figures 6.10 and 6.11 show how, when acclimatised to HDCIS, this participant always rated HDCIS higher on the VAS and closer to what they wanted it to sound like on the MPS. Even when acclimatised to FSP, this participant still rated HDCIS better, although the difference between HDCIS and FSP was no longer statistically significant. With respect to sound quality, the participant rated HDCIS as more pleasant, natural, and rich, and closer to what they would like it to sound than FSP. The participant consistently rated to the left of the mid-point, showing that the sound quality was emptier, duller, and smoother than what they would like it to sound, irrespective of which strategy was being listened to. Another observation from these figures is that the average ratings across the three VAS and across the two MPS were very similar in value. That is, the participant's ratings on each scale were approximately in the same place, regardless of the sound quality being rated.

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[4] The roughness scale was not included as the participant chose not to rate on this scale; she felt she did not have an understanding of the smooth-rough percept.

Table 12: **Ratings when listening to FSP and HDCIS for CI4, with Wilcoxon test results.**
Average ratings for all six rating scales, and the averaged-VAS and averaged-MPS are shown, when acclimatised to each processing strategy. Because an effect of acclimatisation was measured, the separate acclimatised to FSP and HDCIS data is discussed.

	Acclimatised to											
	FSP				**HDCIS**				**Combined data**			
	Mean (SD) FSP	**Mean (SD) HDCIS**	**Wilcoxon test† Z**	**p**	**Mean (SD) FSP**	**Mean (SD) HDCIS**	**Wilcoxon test† Z**	**p**	**Mean (SD) FSP**	**Mean (SD) HDCIS**	**Wilcoxon test† Z**	**p**
Pleasantness	2.35 (0.81)	2.45 (0.74)	-0.102	0.919	1.46 (0.31)	2.82 (0.49)	-2.632	0.008*	1.90 (0.75)	2.64 (0.64)	-0.153	0.878
Naturalness	2.40 (0.72)	2.47 (0.76)	-0.153	0.878	1.48 (0.39)	2.88 (0.56)	-2.803	0.005*	1.94 (0.73)	2.67 (0.68)	-2.725	0.006*
Richness	2.43 (0.76)	2.55 (0.83)	-0.153	0.878	1.50 (0.41)	2.79 (0.61)	-2.803	0.005*	1.96 (0.76)	2.67 (0.72)	-2.539	0.011*
Averaged-VAS	2.39 (0.75)	2.49 (0.77)	-0.357	0.721	1.48 (0.35)	2.83 (0.54)	-2.803	0.005*	1.94 (0.74)	2.66 (0.67)	-2.800	0.005*
Fullness	2.21 (0.80)	1.95 (1.00)	-0.459	0.646	3.41 (0.41)	2.00 (0.41)	-2.803	0.005*	2.81 (0.87)	1.98 (0.74)	-2.838	0.005*
Sharpness	2.17 (0.71)	1.91 (1.00)	-0.663	0.508	3.20 (0.37)	1.84 (0.52)	-2.805	0.005*	2.69 (0.76)	1.87 (0.78)	-2.950	0.003*
Roughness												
Averaged-MPS	2.19 (0.75)	1.93 (1.00)	-0.561	0.575	3.30 (0.36)	1.92 (0.45)	-2.803	0.005*	2.75 (0.81)	1.92 (0.75)	-2.875	0.004*

* indicates those values which are significant ($p \leq 0.05$).

†The Wilcoxon test compared the mean FSP and HDCIS ratings for each rating scale and the averaged-VAS and averaged-MPS.

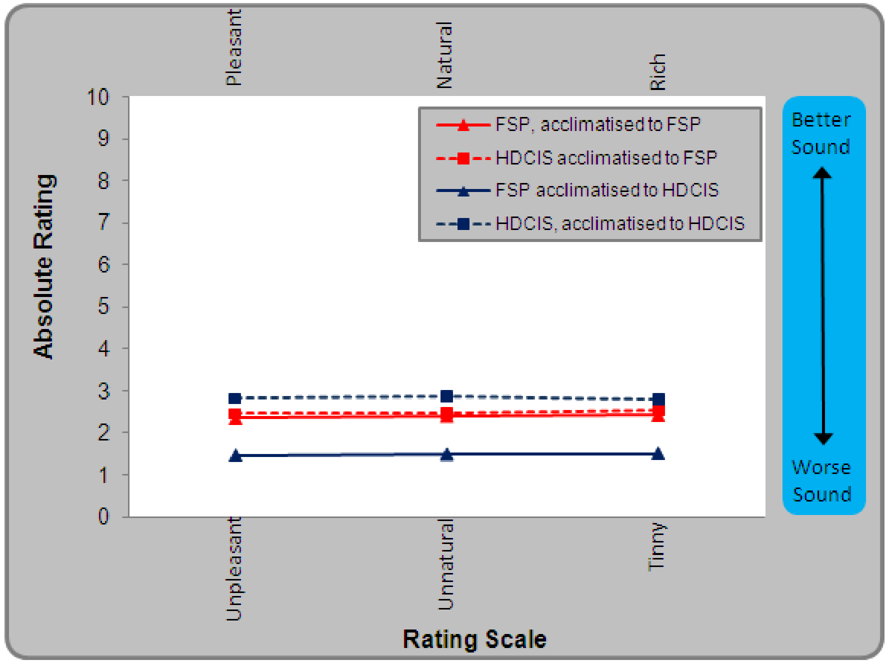

Figure 6.10: The absolute ratings on the VAS for participant CI4.
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

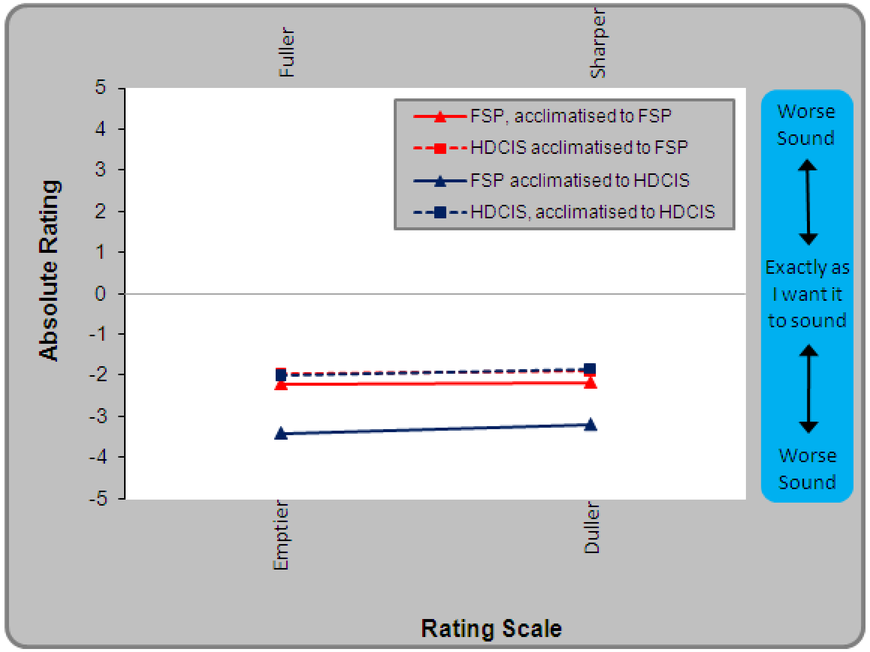

Figure 6.11: The absolute ratings on the fullness and sharpness scales for participant CI4.
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

Participant CI5

As there was a significant acclimatisation effect for this participant reported in Section 6.2.2, the separated 'acclimatised to FSP/HDCIS' data will be referred to in Table 13. Significant differences between FSP and HDCIS are shown for all rating scales when the participant is acclimatised to FSP, and for the VAS when acclimatised to HDCIS; however, the direction of preference was not consistent. For the VAS, the participant consistently preferred HDCIS regardless of which strategy he was acclimatised to. For the MPS, when acclimatised to FSP, the participant preferred FSP; there were no significant differences on the MPS when acclimatised to HDCIS. This is shown in Table 13 by higher mean ratings provided with HDCIS for the pleasantness, naturalness, and richness scales, and values closer to zero (i.e. 'exactly as I want it to sound') when listening to FSP for the fullness, sharpness and roughness scales. As would be expected, the averaged-VAS and averaged-MPS also reflect these trends. These observations can also be seen in Figures 6.12 and 6.13. In other words, on the VAS, irrespective of which strategy he was acclimatised to, this participant consistently rated FSP as less pleasant, less natural and less rich. The mean MPS ratings indicate the sound to be fuller, sharper and smoother than the participant would like it to sound, irrespective of which strategy he was listening to, or was acclimatised to; however, when acclimatised to FSP, FSP was rated significantly closer on the MPS to how the participant would like it to sound when compared to HDCIS.

Table 13: **Ratings when listening to FSP and HDCIS for CI5, with Wilcoxon test results.**
Average ratings for all six rating scales, and the averaged-VAS and averaged-MPS are shown, when acclimatised to each processing strategy. Because an effect of acclimatisation was measured, the separate acclimatised to FSP and HDCIS data is discussed.

	Acclimatised to								Combined data			
	FSP				HDCIS							
	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test† Z	p	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test† Z	p	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test† Z	p
Pleasantness	7.22 (0.88)	8.15 (0.82)	-2.703	0.007*	6.35 (0.84)	7.05 (0.78)	-3.211	0.001*	6.79 (0.95)	7.60 (0.96)	-2.666	0.008*
Naturalness	7.25 (0.92)	8.39 (0.72)	-2.666	0.008*	6.35 (0.77)	7.19 (0.74)	-2.497	0.013*	6.80 (0.94)	7.79 (0.94)	-3.702	0.000*
Richness	7.40 (1.02)	8.12 (0.80)	-2.397	0.017*	6.34 (0.69)	7.30 (0.83)	-2.599	0.009*	6.87 (1.01)	7.71 (0.90)	-3.584	0.000*
Averaged-VAS	7.29 (0.92)	8.22 (0.77)	-2.701	0.007*	6.34 (0.74)	7.18 (0.75)	-2.395	0.017*	6.82 (0.95)	7.70 (0.91)	-3.659	0.000*
Fullness	0.52 (0.94)	1.66 (1.14)	-2.380	0.017*	0.09 (0.20)	0.30 (0.40)	-1.572	0.116	0.31 (0.70)	0.98 (1.08)	-2.919	0.004*
Sharpness	0.34 (0.72)	1.29 (1.25)	-2.366	0.018*	0.00 (0.00)	0.06 (0.18)	-1.000	0.317	0.17 (0.52)	0.68 (1.08)	-2.524	0.012*
Roughness	0.33 (0.72)	0.94 (0.79)	-2.521	0.012*	0.31 (0.44)	0.33 (0.36)	0.000	1.000	0.32 (0.58)	0.64 (0.68)	-1.752	0.080
Averaged-MPS	0.40 (0.79)	1.30 (1.03)	-2.521	0.012*	0.14 (0.20)	0.23 (0.28)	-0.356	0.722	0.27 (0.57)	0.76 (0.92)	-2.415	0.016*

* indicates those values which are significant ($p \leq 0.05$).
†The Wilcoxon test compared the mean FSP and HDCIS ratings for each rating scale and the averaged-VAS and averaged-MPS.

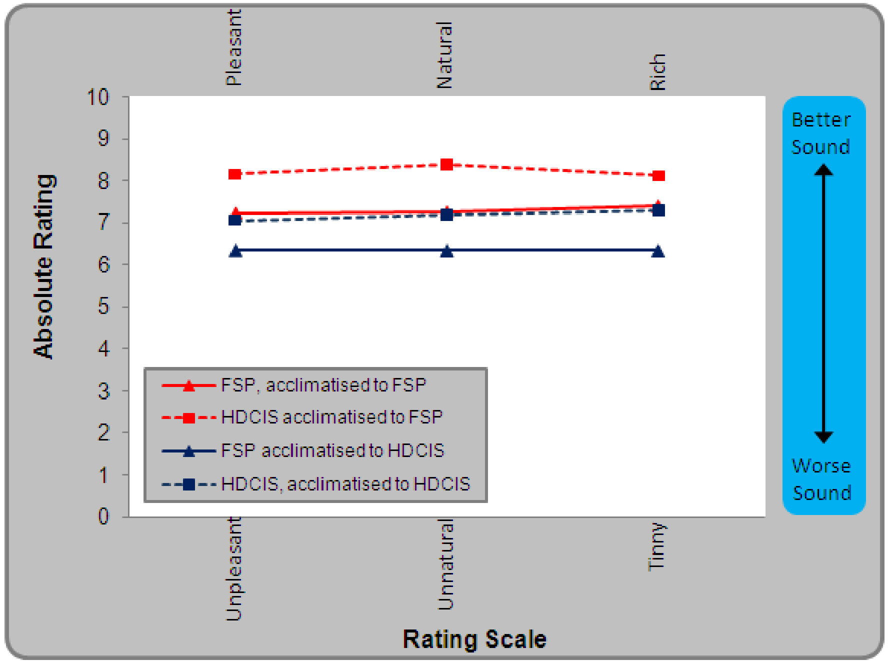

Figure 6.12 : The absolute ratings on the VAS for participant CI5.
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

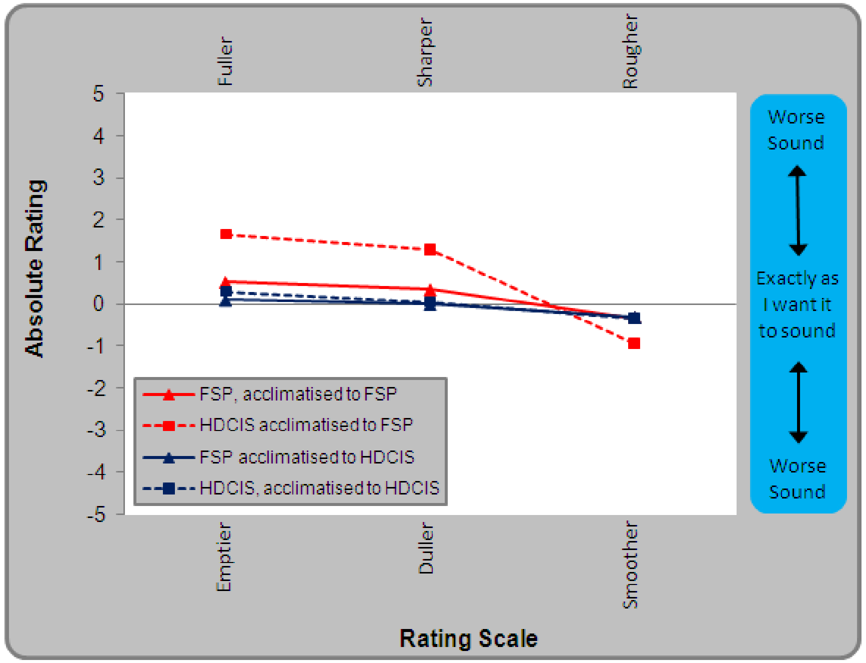

Figure 6.13: The absolute ratings on the MPS for participant CI5.
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

Average data across all five participants.

As there was a significant acclimatisation effect for the group data reported in Section 6.2.2, the separated 'acclimatised to FSP/HDCIS' data will be considered in Table 14. The data shows that the group rated FSP significantly higher than HDCIS for the fullness, sharpness, roughness, and averaged-MPS, when acclimatised to FSP. That is, the mean fullness, sharpness, and roughness ratings were closer to the perfect sound (i.e. closer to zero) when listening to FSP. Figures 6.14 and 6.15 show the trend of preferring FSP when acclimatised to FSP, and preferring HDCIS when acclimatised to HDCIS, although the ratings for FSP and HDCIS in the latter situation were not significantly different. As a group, the average ratings clustered in the middle 40% of the scales, and for the MPS the average ratings indicated that the music sounded emptier than what the participants wanted it to sound like, irrespective of the strategy used or acclimatised to. On the sharpness and roughness scales, when acclimatised to FSP, the sound for HDCIS was sharper and rougher than FSP; however, when acclimatised to HDCIS, both FSP and HDCIS were rated as duller and smoother than the group wanted it to sound like.

Table 14: Ratings when listening to FSP and HDCIS for the average group data, with Wilcoxon test results.
Average ratings for all six rating scales, and the averaged-VAS and averaged-MPS are shown, when acclimatised to each processing strategy. Because an effect of acclimatisation was measured for the group data, the separate acclimatised to FSP and HDCIS data is discussed.

	Acclimatised to											
	FSP				HDCIS				Combined data			
	Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test†		Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test†		Mean (SD) FSP	Mean (SD) HDCIS	Wilcoxon test†	
			Z	p			Z	p			Z	p
Pleasantness	6.14 (0.49)	5.57 (0.90)	-1.274	0.203	4.75 (0.45)	5.00 (0.44)	-0.635	0.526	5.44 (0.85)	5.29 (0.75)	-1.478	0.139
Naturalness	6.07 (0.47)	5.48 (0.91)	-1.478	0.139	4.65 (0.32)	4.97 (0.37)	-1.682	0.093	5.36 (0.83)	5.22 (0.73)	-0.821	0.411
Richness	5.94 (0.49)	5.37 (0.94)	-1.784	0.074	4.15 (0.29)	4.44 (0.41)	-1.478	0.139	5.05 (1.00)	4.91 (0.85)	-0.747	0.455
Averaged-VAS	6.05 (0.43)	5.48 (0.90)	-1.478	0.139	4.52 (0.33)	4.80 (0.34)	-1.886	0.059	5.28 (0.87)	5.14 (0.75)	-0.635	0.526
Fullness	0.87 (0.32)	1.40 (0.31)	-2.293	0.022*	1.00 (0.27)	1.04 (0.49)	-0.561	0.575	0.93 (0.30)	1.22 (0.44)	-2.221	0.026*
Sharpness	0.85 (0.21)	1.39 (0.44)	-2.497	0.013*	1.02 (0.31)	0.96 (0.31)	-0.051	0.959	0.93 (0.27)	1.17 (0.43)	-2.053	0.040*
Roughness	0.65 (0.31)	1.17 (0.47)	-2.090	0.037*	0.58 (0.39)	0.83 (0.37)	-1.172	0.241	0.61 (0.34)	1.00 (0.45)	-2.427	0.015*
Averaged-MPS	0.79 (0.23)	1.32 (0.36)	-2.497	0.013*	0.86 (0.28)	0.94 (0.35)	-0.663	0.508	0.83 (0.25)	1.13 (0.40)	-2.277	0.023*

* indicates those values which are significant ($p \leq 0.05$)

†The Wilcoxon test compared the mean FSP and HDCIS ratings for each rating scale and the averaged-VAS and averaged-MPS.

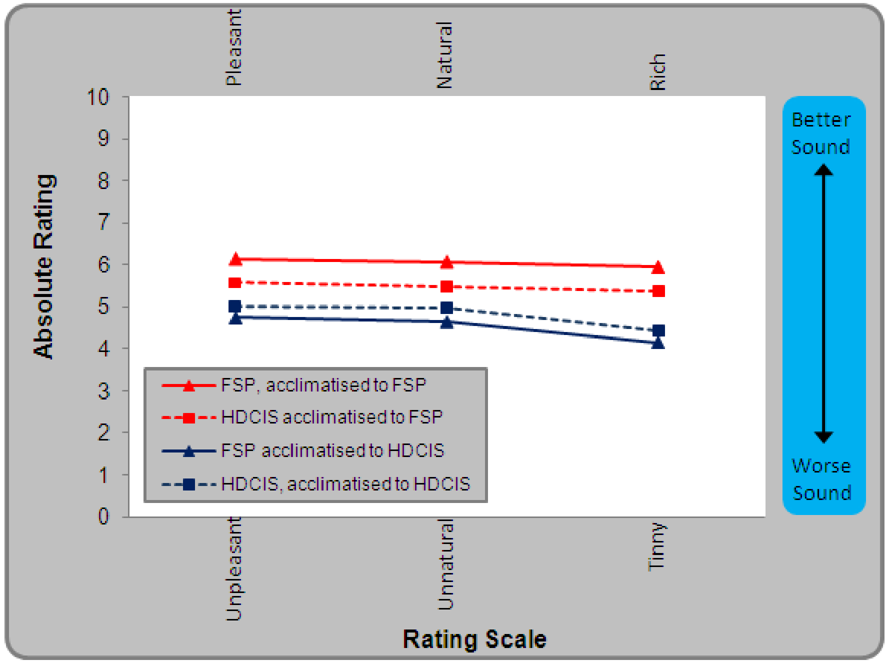

Figure 6.14: The absolute ratings on the VAS, for the averaged group data.
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

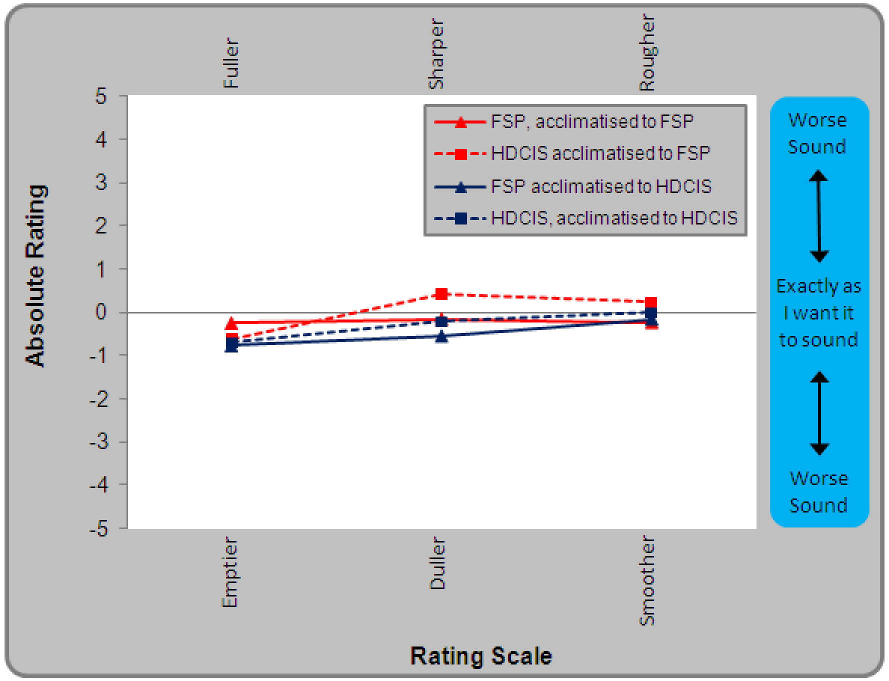

Figure 6.15: The absolute ratings on the MPS for the averaged group data.
Average FSP and HDCIS ratings are shown, when acclimatised to FSP and HDCIS.

6.2.3 Hypothesis Three – Music Genre

CI recipients will rate the sound quality of familiar songs to be higher than obscure songs.

The ratings provided were analysed to determine whether genre had an effect on music quality ratings. This was carried out in two steps. Firstly a Friedman test was carried out to identify whether there were significant differences ($p \leq 0.05$) between the ratings provided across the four genres. This analysis was done for each separate rating scale along with the averaged-VAS and averaged-MPS, and was conducted for each individual as well as the overall averaged group data. The data used differs slightly from that in sections 6.2.2 and 6.2.3. In the previous sections, the data for the MPS indicated how far from the midpoint the rating was, but not the direction this deviation was (i.e. to the left or right of the mid-point). In order to answer this third hypothesis, the direction of the rating is also important, as the absolute distance between ratings and not just its distance from the midpoint is of significance. In order to allow for this, the mid-point was given a value of zero, with negative values indicating that the rating provided was to the left of the mid-point (emptier, duller or smoother) and positive values showing a rating to the right (fuller, sharper or rougher). The baseline, and subsequent two testing sessions provided three pairs of ratings for each genre, which were used in the data analyses. The results of these analyses are shown in each participant's section, with a degree of freedom (df) value of 3 in all cases. Subsequent to the Friedman test, if a significant effect of genre was found, post-hoc Wilcoxon signed-ranks tests were used to investigate where the differences lay, the results of which are shown in the respective sections. To account for the multiple comparisons, a Bonferroni-adjusted significance value of

$p \leq 0.00833$[5] was used. That is, the results of the post-hoc pairwise comparisons was taken to be statistically significant if $p \leq 0.00833$.

Participant CI1

For participant CI1, as shown in Table 15, the results of the Friedman test showed significant differences on the pleasantness, naturalness, richness, and averaged-VAS. Post-hoc analyses (Tables 16 - 19) showed that for the pleasantness, naturalness, and averaged-VAS, the classical genre was rated significantly higher than the other three genres. There were no other significant differences between any of the other genres. For the richness scale, post-hoc analysis (Table 18) showed a significant difference between the classical and common, and between the common and country and western genres.

Table 15: Mean values for each genre, and results of Friedman analysis of participant CI1's ratings.
Mean ratings for the classical, modern, country and western (CW) and common genres are provided for each rating scale, the averaged-VAS, and the averaged-MPS. The Friedman test results (chi-square and p-values) compare these means.

	Mean (SD) Classical	Mean (SD) Modern	Mean (SD) CW	Mean (SD) Common	Friedman test	
					chi-square	p
Pleasantness	9.19 (0.50)	7.75 (0.76)	7.81 (0.64)	8.08 (0.90)	16.900	0.001*
Naturalness	8.82 (0.81)	6.82 (1.43)	7.66 (0.67)	6.74 (1.75)	17.500	0.001*
Richness	7.28 (1.84)	6.21 (1.22)	6.98 (1.47)	5.89 (1.42)	12.900	0.005*
Averaged-VAS	8.43 (0.73)	6.93 (0.90)	7.48 (0.73)	6.91 (0.95)	18.100	0.000*
Fullness	-0.15 (0.28)	-0.29 (0.58)	0.20 (0.63)	-0.29 (0.46)	6.606	0.086
Sharpness	-0.13 (0.25)	-0.47 (0.5)	-0.31 (0.30)	-0.22 (0.45)	6.103	0.107
Roughness	0.11 (0.26)	0.18 (0.64)	0.49 (0.70)	0.29 (0.44)	5.722	0.126
Averaged-MPS	-0.06 (0.09)	-0.19 (0.44)	0.13 (0.44)	-0.07 (0.34)	2.602	0.457

* indicates those values which are significant ($p \leq 0.05$).

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[5] The Bonferroni method adjusts the p-value to be: 0.05/n where n equals the number of comparisons performed. i.e. 0.05/6 = 0.008333

Table 16: Results of post-hoc analyses for the pleasantness scale for participant CI1. The mean values for each genre in Table 15 were compared using repeated Wilcoxon signed-ranks tests.

	Classical	Modern		CW		Common	
		Wilcoxon test results					
		Z	p	Z	p	Z	p
Classical		-2.981	0.003*	-3.059	0.002*	-2.667	0.008*
Modern				0.000	1.000	-2.119	0.034
CW						-.941	0.347
Common							

*indicates those means which are significantly different (p ≤ 0.008333)

Table 17: Results of post-hoc analyses for the naturalness scale for participant CI1. The mean values for each genre in Table 15 were compared using repeated Wilcoxon signed-ranks tests.

	Classical	Modern		CW		Common	
		Wilcoxon test results					
		Z	p	Z	p	Z	p
Classical		-2.903	0.004*	-2.746	0.006*	-2.903	0.004*
Modern				-2.158	0.031	-0.157	0.875
CW						-1.726	0.084
Common							

*indicates those means which are significantly different (p ≤ 0.008333)

Table 18: Results of post-hoc analyses for the richness scale for participant CI1. The mean values for each genre in Table 15 were compared using repeated Wilcoxon signed-ranks tests.

	Classical	Modern		CW		Common	
		Wilcoxon test		Wilcoxon test		Wilcoxon test	
		Z	p	Z	p	Z	p
Classical		-1.647	0.099	-1.255	0.209	-2.904	0.004*
Modern				-1.883	0.060	-1.647	0.099
CW						-2.746	0.006*
Common							

*indicates those means which are significantly different (p ≤ 0.008333)

Table 19: Results of post-hoc analyses for the averaged-VAS for participant CI1. The mean values for each genre in Table 15 were compared using repeated Wilcoxon signed-ranks tests.

	Classical	Modern		CW		Common	
		Wilcoxon test		Wilcoxon test		Wilcoxon test	
		Z	p	Z	p	Z	p
Classical		-2.824	0.005*	-2.824	0.005*	-3.059	0.002*
Modern				-1.961	0.050	0.000	1.000
CW						-2.040	0.041
Common							

*indicates those means which are significantly different (p ≤ 0.008333)

Participant CI2

As shown in Table 20, the data for participant CI2 showed significant differences between genres for the pleasantness, naturalness, and averaged-VAS. Post-hoc analyses shown in Tables 21 - 23, however, did not show any of the individual pairwise comparisons to be statistically significant. That is, although there was an effect of genre on music quality ratings for the pleasantness, naturalness, and averaged-VAS, one genre was not rated significantly higher than another.

Table 20: Mean values for each genre, and results of Friedman analysis of participant CI2's ratings.
Mean ratings for the classical, modern, country and western (CW) and common genres are provided for each rating scale, the averaged-VAS, and the averaged-MPS. The Friedman test results (chi-square and p-values) compare these means.

	Mean (SD) Classical	Mean (SD) Modern	Mean (SD) CW	Mean (SD) Common	Friedman test	
					chi-square	p
Pleasantness	5.57 (2.34)	3.41 (2.22)	4.08 (2.35)	5.18 (2.42)	9.706	0.021*
Naturalness	5.36 (2.38)	3.04 (2.15)	3.87 (2.05)	4.91 (2.35)	13.200	0.004*
Richness	4.99 (2.51)	3.07 (2.15)	3.84 (2.48)	4.86 (2.72)	4.160	0.245
Averaged-VAS	5.31 (2.30)	3.18 (2.10)	3.93 (2.27)	4.98 (2.46)	8.400	0.038*
Fullness	-0.90 (1.14)	-1.26 (2.27)	-0.88 (1.67)	-0.60 (1.92)	1.645	0.649
Sharpness	0.41 (1.62)	0.58 (2.00)	1.21 (1.27)	0.01 (2.07)	1.250	0.741
Roughness	0.86 (1.10)	1.63 (1.18)	1.29 (1.02)	1.00 (1.57)	2.066	0.559
Averaged-MPS	0.12 (0.79)	0.32 (0.78)	0.54 (0.34)	0.14 (0.91)	4.237	0.237

* indicates those values which are significant (p ≤ 0.05).

Table 21: Results of post-hoc analyses for the pleasantness scale for participant CI2.
The mean values for each genre in Table 20 were compared using repeated Wilcoxon signed-ranks tests. No significant results were found (p ≤ 0.008333)

	Classical	**Modern**		**CW**		**Common**	
		Wilcoxon test results					
		Z	p	Z	p	Z	p
Classical		-2.312	0.021	-1.412	0.158	-0.157	0.875
Modern				-1.255	0.209	-2.118	0.034
CW						-1.648	0.099
Common							

Table 22: **Results of post-hoc analyses for the naturalness scale for participant CI2.** The mean values for each genre in Table 20 were compared using repeated Wilcoxon signed-ranks tests. No significant results were found ($p \leq 0.008333$)

	Classical	Modern		CW		Common	
		Wilcoxon test results					
		Z	p	Z	p	Z	p
Classical		-2.275	0.023	-1.412	0.158	-0.392	0.695
Modern				-2.040	0.041	-2.353	0.019
CW						-1.804	0.071
Common							

Table 23: **Results of post-hoc analyses for the averaged-VAS for participant CI2.** The mean values for each genre in Table 20 were compared using repeated Wilcoxon signed-ranks tests. No significant results were found ($p \leq 0.008333$)

	Classical	Modern		CW		Common	
		Wilcoxon test results					
		Z	p	Z	p	Z	p
Classical		-2.118	0.034	-1.334	0.182	0.000	1.000
Modern				-1.961	0.050	-2.275	0.023
CW						-1.647	0.099
Common							

Participant CI3

As shown in Table 24, the data for participant CI3 showed no significant effect of genre for any of the rating scales, indicating that for this participant, genre had no effect on music quality ratings.

Table 24: **Mean values for each genre, and results of Friedman analysis of participant CI3's ratings.** Mean ratings for the classical, modern, country and western (CW) and common genres are provided for each rating scale, the averaged-VAS, and the averaged-MPS. The Friedman test results (chi-square and p-values) compare these means.

	Mean (SD) Classical	Mean (SD) Modern	Mean (SD) CW	Mean (SD) Common	Friedman test	
					chi-square	p
Pleasantness	3.71 (2.63)	4.92 (2.24)	4.79 (2.53)	5.82 (2.05)	1.900	0.593
Naturalness	3.17 (2.44)	4.95 (2.41)	4.22 (2.76)	5.48 (2.07)	6.900	0.075
Richness	3.60 (2.58)	4.44 (2.17)	4.32 (3.01)	4.38 (2.05)	0.025	0.999
Averaged-VAS	3.49 (2.42)	4.77 (2.09)	4.44 (2.70)	5.23 (1.75)	1.700	0.637
Fullness	-0.35 (2.54)	-0.66 (1.24)	-0.29 (1.8)	0.21 (1.43)	1.689	0.639
Sharpness	-0.16 (2.08)	0.33 (1.51)	0.63 (1.46)	-0.42 (1.13)	5.900	0.117
Roughness	-0.62 (2.57)	-0.26 (1.73)	-1.00 (1.42)	-0.46 (1.19)	2.143	0.543
Averaged-MPS	-0.38 (1.19)	-0.20 (0.72)	-0.22 (0.90)	-0.22 (0.71)	0.000	1.000

Participant CI4

As shown in Table 25, a significant effect of genre for the fullness and averaged-MPS[6] was found for participant CI4. Post-hoc analyses shown in Tables 26 and 27 identified a significant difference between the classical and country and western genres on the averaged-MPS only. Therefore, for this participant, there was some influence of genre on the fullness and averaged-MPS of music quality; however, one genre was generally not rated significantly higher than the others.

Table 25: **Mean values for each genre, and results of Friedman analysis of participant CI4's ratings.**
Mean ratings for the classical, modern, country and western (CW) and common genres are provided for each rating scale, the averaged-VAS, and the averaged-MPS. The Friedman test results (chi-square and p-values) compare these means.

	Mean (SD) Classical	Mean (SD) Modern	Mean (SD) CW	Mean (SD) Common	Friedman test chi-square	Friedman test p
Pleasantness	2.12 (0.82)	2.41 (0.76)	2.42 (0.87)	2.34 (0.57)	0.900	0.825
Naturalness	1.97 (1.00)	2.41 (0.70)	2.47 (0.90)	2.43 (0.62)	4.563	0.207
Richness	2.06 (0.82)	2.52 (0.70)	2.48 (0.97)	2.58 (0.69)	6.501	0.090
Averaged-VAS	2.05 (0.86)	2.45 (0.71)	2.46 (0.91)	2.45 (0.62)	3.100	0.376
Fullness	-3.00 (0.86)	-2.22 (1.00)	-2.19 (0.83)	-2.34 (0.60)	8.345	0.039*
Sharpness	-2.86 (0.83)	-2.14 (0.95)	-2.07 (0.80)	-2.34 (0.61)	6.100	0.107
Roughness	▨	▨	▨	▨	▨	▨
Averaged-MPS	-2.93 (0.84)	-2.18 (0.97)	-2.13 (0.79)	-2.34 (0.60)	9.100	0.028*

* indicates those values which are significant (p ≤ 0.05).

Table 26: **Results of post-hoc analyses for the fullness scale for participant CI4.**
The mean values for each genre in Table 29 were compared using repeated Wilcoxon signed-ranks tests. No significant results were found (p ≤ 0.008333)

	Classical	Modern		CW		Common	
		Wilcoxon test results					
		Z	p	Z	p	Z	p
Classical		-2.197	0.028	-2.510	0.012	-2.401	0.016
Modern				-1.177	0.239	-0.079	0.937
CW						-0.235	0.814
Common							

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[6] The roughness scale was not included as the participant chose not to rate on this scale; she felt she did not have an understanding of the smooth-rough percept.

Table 27: Results of post-hoc analyses for the averaged-MPS for participant CI4.
The mean values for each genre in Table 29 were compared using repeated Wilcoxon signed-ranks tests.

	Classical	Modern		CW		Common	
		Wilcoxon test results					
		Z	p	Z	p	Z	p
Classical		-2.118	0.034	-2.824	0.005*	-2.315	0.021
Modern				-0.981	0.327	-0.314	0.754
CW						-0.235	0.814
Common							

*indicates those means which are significantly different (p ≤ 0.008333)

Participant CI5

As shown in Table 28, the data for participant CI5 showed no significant effect of genre for any of the rating scales, indicating that for this participant, genre had no effect on music quality ratings.

Table 28: Mean values for each genre, and results of Friedman analysis of participant CI5's ratings.
Mean ratings for the classical, modern, country and western (CW) and common genres are provided for each rating scale, the averaged-VAS, and the averaged-MPS. The Friedman test results (chi-square and p-values) compare these means.

	Mean (SD) Classical	Mean (SD) Modern	Mean (SD) CW	Mean (SD) Common	Friedman test chi-square	Friedman test p
Pleasantness	7.19 (0.84)	7.42 (1.09)	7.61 (1.10)	7.20 (0.85)	3.300	0.348
Naturalness	7.19 (0.95)	7.52 (1.02)	7.70 (1.21)	7.35 (0.81)	3.051	0.384
Richness	7.18 (0.99)	7.42 (1.11)	7.68 (1.14)	7.44 (0.74)	3.100	0.376
Averaged-VAS	7.19 (0.92)	7.45 (1.06)	7.66 (1.15)	7.33 (0.76)	3.400	0.334
Fullness	0.88 (1.23)	0.45 (0.67)	0.21 (0.54)	0.74 (1.15)	4.753	0.191
Sharpness	0.84 (1.29)	0.29 (0.59)	0.08 (0.26)	0.78 (1.09)	7.339	0.062
Roughness	-0.66 (0.91)	-0.26 (0.40)	-0.12 (0.23)	-0.37 (0.62)	3.085	0.379
Averaged-MPS	0.36 (0.65)	0.16 (0.30)	0.06 (0.21)	0.38 (0.62)	2.258	0.521

Average data across all five participants.

The averaged group data, as shown in Table 29, showed no significant effect of genre for any of the rating scales.

Table 29: Mean values for each genre, and results of Friedman analysis of the averaged group's ratings.
Mean ratings for the classical, modern, country and western (CW) and common genres are provided for each rating scale, the averaged-VAS, and the averaged-MPS. The Friedman test results (chi-square and p-values) compare these means.

	Mean (SD) Classical	Mean (SD) Modern	Mean (SD) CW	Mean (SD) Common	Friedman test	
					chi-square	p
Pleasantness	5.59 (0.78)	5.17 (0.78)	5.30 (0.83)	5.73 (0.89)	1.500	0.682
Naturalness	5.33 (0.82)	4.93 (0.76)	5.15 (0.79)	5.40 (0.67)	3.300	0.348
Richness	4.79 (0.69)	4.59 (0.58)	4.85 (0.93)	4.83 (0.73)	2.100	0.552
Averaged-VAS	5.24 (0.74)	4.90 (0.66)	5.10 (0.83)	5.32 (0.69)	5.200	0.158
Fullness	-1.65 (0.63)	-1.67 (0.57)	-1.56 (0.55)	-1.33 (0.67)	1.900	0.593
Sharpness	-1.33 (0.80)	-1.09 (0.70)	-0.98 (0.57)	-1.33 (0.59)	6.100	0.107
Roughness	-1.07 (0.62)	-0.66 (0.43)	-0.88 (0.34)	-0.91 (0.50)	6.529	0.089
Averaged-MPS	-1.35 (0.33)	-1.14 (0.34)	-1.14 (0.25)	-1.19 (0.32)	6.600	0.086

6.2.4 Hypothesis Four – Song Familiarity

CI recipients will rate modern songs higher than classical, country and western, or common songs.

Because the familiar test items in the MQRTB were matched with an obscure equivalent, paired t-tests were conducted to compare the familiar and obscure items for each individual rating scale, as well as the averaged-VAS and averaged-MPS. A Wilcoxon signed-ranks test was also conducted to assess whether there were any differences between the ratings for the two favourite items compared to the four familiar items (see Appendix G for the participant's favourite songs). As with the previous section, the data used for the MPS took into account the rating direction using negative and positive values. A value of zero indicates that the sound quality was exactly as the participant wanted it to sound. A negative value showed that the rating was to the left of the mid-point and sounded emptier, duller or smoother than the preferred sound, whereas a positive value showed that the rating was to the right of the mid-point and sounded fuller, sharper or rougher than the preferred sound. The results for each individual participant, and the averaged group data are shown below. The degree of freedom (df) for all tests equalled 23.

Participant CI1

Table 30 displays the mean ratings for all of the individual scales and the averaged-VAS and averaged-MPS for the familiar and obscure songs in the MQRTB provided by participant CI1, along with the results from the paired t-test analysis. There was a significant difference between the ratings for familiar and obscure songs on the pleasantness scale, with the familiar songs being rated as significantly more pleasant. No significant differences were found for any individual scales, or the averaged-VAS or averaged-MPS, between ratings for the favourite versus familiar items.

Table 30: Participant CI1's means, standard deviations (in parentheses), and paired t-test results across each rating scale for familiar and obscure songs.

	Mean (SD) Familiar	Mean (SD) Obscure	Paired t-test	
			t	p
Pleasantness	8.51 (0.72)	7.91 (0.99)	2.84	0.009*
Naturalness	7.38 (1.61)	7.64 (1.34)	-1.11	0.281
Richness	6.53 (1.44)	6.64 (1.70)	-0.50	0.621
Averaged-VAS	7.48 (0.91)	7.40 (1.14)	0.43	0.668
Fullness	-0.16 (0.38)	-0.10 (0.65)	-0.40	0.690
Sharpness	-0.22 (0.36)	-0.34 (0.43)	1.08	0.291
Roughness	0.40 (0.47)	0.13 (0.59)	2.06	0.051
Averaged-MPS	0.01 (0.23)	-0.10 (0.46)	1.14	0.264

* indicates those values which are significant (p ≤ 0.05).

Participant CI2

Table 31 displays participant CI2's mean ratings for all of the individual scales and the averaged-VAS and averaged-MPS for the familiar and obscure songs in the MQRTB, along with the test results from the paired t-test analysis. There were no significant differences between the ratings for familiar and obscure songs on any of the rating scales. That is, song familiarity had no effect on music quality ratings for this participant. No significant differences were found for any individual scales, or the averaged scales, between ratings for the favourite versus familiar items.

Table 31: **Participant CI2's means, standard deviations (in parentheses), and paired t-test results across each rating scale for familiar and obscure songs.**

	Mean (SD) Familiar	Mean (SD) Obscure	Paired t-test	
			t	p
Pleasantness	4.78 (2.42)	4.34 (2.44)	0.87	0.391
Naturalness	4.60 (2.31)	3.99 (2.40)	1.13	0.272
Richness	4.65 (2.43)	3.74 (2.57)	1.64	0.115
Averaged-VAS	4.67 (2.35)	4.02 (2.40)	1.28	0.212
Fullness	-1.09 (1.66)	-0.73 (1.87)	-0.83	0.413
Sharpness	0.77 (1.61)	1.34 (1.92)	0.98	0.335
Roughness	1.16 (1.31)	1.24 (1.17)	-0.20	0.841
Averaged-MPS	1.28 (0.79)	1.28 (0.70)	-0.02	0.984

Participant CI3

Table 32 displays the mean ratings for all of the individual scales and the averaged-VAS and averaged-MPS for the familiar and obscure songs in the MQRTB for participant CI3, along with the test results from the paired t-test analysis. For this participant, there were significant differences on the pleasantness, naturalness, and averaged-VAS, with the obscure songs being rated more pleasant and natural. No significant differences were found for any individual scales, or the averaged scales, between ratings for the favourite versus familiar items.

Table 32: **Participant CI3's means, standard deviations (in parentheses), and paired t-test results across each rating scale for familiar and obscure songs.**

	Mean (SD) Familiar	Mean (SD) Obscure	Paired t-test	
			t	p
Pleasantness	4.06 (2.36)	5.56 (2.28)	-2.29	0.031*
Naturalness	3.42 (2.24)	5.49 (2.38)	-3.28	0.003*
Richness	3.55 (2.22)	4.82 (2.50)	-1.88	0.073
Averaged-VAS	3.68 (2.08)	5.29 (2.24)	-2.63	0.015*
Fullness	-0.55 (2.07)	0.00 (1.45)	-1.27	0.215
Sharpness	1.45 (1.63)	-0.26 (1.49)	1.50	0.130
Roughness	-0.56 (2.10)	-0.61 (1.41)	0.09	0.931
Averaged-MPS	-0.22 (0.67)	-0.29 (1.06)	0.27	0.790

* indicates those values which are significant ($p \leq 0.05$).

Participant CI4

Table 33 displays the mean ratings for all of the individual scales and the averaged-VAS and averaged-MPS for the familiar and obscure songs in the MQRTB provided by participant CI4, along with the test results from the paired t-test analysis. There were significant differences between familiar and obscure songs on the pleasantness, naturalness, richness, and averaged-VAS, with familiar songs being rated as more pleasant, natural and rich for this participant. No significant differences were found for any of the individual scales, or averaged scales, between ratings for the favourite versus familiar items.

Table 33: Participant CI4's means, standard deviations (in parentheses), and paired t-test results across each rating scale for familiar and obscure songs.

	Mean (SD) Familiar	Mean (SD) Obscure	Paired t-test	
			t	p
Pleasantness	2.62 (0.77)	2.03 (0.61)	3.50	0.002*
Naturalness	2.66 (0.79)	1.98 (0.71)	3.42	0.002*
Richness	2.73 (0.78)	2.08 (0.70)	3.23	0.004*
Averaged-VAS	2.67 (0.77)	2.03 (0.66)	1.54	0.002*
Fullness	-2.27 (0.74)	2.39 (0.98)	1.96	0.062
Sharpness	-2.26 (0.72)	-2.45 (0.95)	1.06	0.301
Roughness†	▨	▨	▨	▨
Averaged-MPS	-2.27 (0.72)	-2.53 (0.95)	1.537	0.138

* indicates those values which are significant ($p \leq 0.05$).
† The roughness scale was not rated by the participant.

Participant CI5

Table 34 displays participant CI5's mean ratings for all of the individual scales and the averaged-VAS and averaged-MPS for the familiar and obscure songs in the MQRTB, along with the test results from the paired t-test analysis. There were no significant differences between familiar and obscure songs on any of the rating scales. That is, song familiarity had no effect on music quality ratings for this participant. As shown in Table 35, this participant rated their favourite songs significantly higher that the familiar songs on the naturalness, richness, and averaged-VAS.

Table 34: **Participant CI5's means, standard deviations (in parentheses), and paired t-test results across each rating scale for familiar and obscure songs.**

	Mean (SD) Familiar	Mean (SD) Obscure	Paired t-test t	p
Pleasantness	7.55 (0.97)	7.16 (0.93)	1.70	0.102
Naturalness	7.62 (1.03)	7.26 (0.94)	1.65	0.112
Richness	7.55 (1.08)	7.31 (0.90)	0.96	0.347
Averaged-VAS	7.57 (1.01)	7.24 (0.91)	1.46	0.159
Fullness	1.63 (1.07)	1.51 (0.84)	0.47	0.642
Sharpness	1.57 (1.02)	1.42 (0.85)	0.57	0.574
Roughness	-0.37 (0.60)	-0.33 (0.64)	-0.30	0.769
Averaged-MPS	1.28 (0.54)	1.20 (0.44)	0.55	0.591

Table 35: **Participant CI5's means, standard deviations (in parentheses), and Wilcoxon test results comparing familiar and favourite songs.**

	Mean (SD) Familiar	Mean (SD) Favourite	Wilcoxon test† Z	p
Naturalness	7.62 (1.03)	8.10 (1.15)	-2.040	0.041*
Richness	7.55 (1.08)	8.07 (1.01)	-2.276	0.023*
Averaged-VAS	7.57 (1.01)	8.06 (1.11)	-1.961	0.050*

* indicates those values which are significant ($p \leq 0.05$).
†The Wilcoxon test compared the mean familiar and favourite ratings for each rating scale and the averaged-VAS and averaged-MPS. Only the significant results are shown.

Average data across all five participants.

Table 36 displays the group means for the familiar and obscure songs in the MQRTB, for the ratings for all individual scales and the averaged-VAS and averaged-MPS, along with the test results from the paired t-test analysis. It shows that for the group there were no significant differences between ratings for familiar and obscure songs on any of the rating scales. That is, song familiarity had no effect on music quality ratings for this group of participants. No significant differences were found for any of the scales, or the averaged-VAS or averaged-MPS, between ratings for the favourite versus familiar items.

Table 36: **The averaged group data means, standard deviations (in parentheses), and paired t-test results across each rating scale for familiar and obscure songs.**

	Mean (SD) Familiar	Mean (SD) Obscure	Paired t-test t	Paired t-test p
Pleasantness	5.50 (0.82)	5.39 (0.84)	0.58	0.566
Naturalness	5.15 (0.72)	5.26 (0.81)	-0.69	0.499
Richness	4.82 (0.64)	4.72 (0.81)	0.60	0.556
Averaged-VAS	5.15 (0.67)	5.12 (0.79)	0.20	0.846
Fullness	-1.62 (0.71)	-1.48 (0.48)	-1.04	0.308
Sharpness	-1.05 (0.70)	-1.32 (0.63)	1.56	0.132
Roughness	-0.89 (0.59)	-0.78 (0.37)	-0.13	0.899
Averaged-MPS	-1.19 (0.33)	-1.22 (0.31)	0.44	0.663

6.3 Speech Perception Scores

Table 37 shows each participant's and the group's percent-correct scores for the speech perception tests conducted, when acclimatised to FSP and HDCIS. Due to a lack of subject numbers no statistical comparison between FSP and HDCIS, or quiet versus noise results were made. Similarly, correlations were not calculated between speech perception scores and MQRTB ratings.

Table 37: **Speech perception scores for each participant, with overall group means and standard deviations.**
Speech perception scores are percent-correct scores for the CNC words tests, and the CUNY-like sentences in quiet and noise (+10dB SNR), when acclimatised to FSP and HDCIS.

	Acclimatised to							
	FSP				HDCIS			
% correct	Phonemes	Words	Sentences in Quiet	Sentences in Noise	Phonemes	Words	Sentences in Quiet	Sentences in Noise
CI1	85.0	78	88.2	60.8	91.0	78	100.0	76.5
CI2	87.8	70	99.0	93.1	84.7	67	100.0	76.5
CI3	60.2	34	97.1	94.1	61.8	32	98.0	90.2
CI4	33.8	10	71.6	61.8	39.6	22	64.7	44.1
CI5	65.0	28	97.1	98.0	57.0	24	99.0	57.8
Mean	66.4	44.0	90.6	81.6	66.8	44.6	92.3	69.0
SD	21.8	28.9	11.4	18.6	21.0	26.0	15.5	18.1

Chapter 7. Discussion

7.1 Introduction

The aims of this study were to develop a music quality rating test battery and use it to compare the music appreciation ratings of CI recipients when listening with the FSP and HDCIS speech processing strategies. It was hypothesised that; (1) familiarity with either FSP or HDCIS will affect the quality ratings of CI recipients, with the processing strategy the participants are acclimatised to being preferred in music quality ratings, (2) CI recipients will prefer the sound of FSP over HDCIS on the rating scales of pleasantness, naturalness, richness, fullness, sharpness, and roughness, (3) CI recipients will rate the sound quality of familiar songs to be higher than obscure songs, and (4) CI recipients will rate modern songs higher than classical, country and western, or common songs. The averaged group's results from this study are consistent with the first two hypotheses, but not the second two. The first two hypotheses are discussed collectively, as the results from hypothesis one impact on the results and interpretation of hypothesis two. Hypotheses three and four are then discussed separately, followed by a discussion of the MQRTB task. This is followed by a general discussion of issues not directly related to the research aims, the clinical implications and limitations of the study, and a summary of the conclusions drawn from the study.

7.2 Comparison of Music Quality Ratings for the FSP and HDCIS Processing Strategies.

7.2.1 Hypotheses One and Two – Strategy Familiarity and Preference

The results for hypothesis one (i.e. acclimatisation) show mixed findings, with participants CI1, CI3, and CI5 showing no significant differences between ratings when listening with FSP and HDICS, after being acclimatised to each strategy. This indicates that acclimatisation to a particular speech processing strategy had no effect on the ratings provided for these participants. Participants CI2 and CI4 showed significant differences between ratings after acclimatising to each processing strategy, as did the averaged group data, consistent with the hypothesis that overall acclimatisation to either FSP or HDCIS has an effect on music quality ratings.

For hypothesis two, the results of this study were also mixed. Two participants (CI1 and CI3) showed no preference for either processing strategy, one participant (CI2) showed a clear preference for FSP, one a clear preference for HDCIS (CI4), and one showed mixed preferences depending on the rating scale (CI5). For the averaged group data, a statistically significant FSP preference was measured on the fullness, sharpness, roughness and averaged-MPS when acclimatised to FSP, consistent with hypothesis two. This also supports the finding for hypothesis one of an acclimatisation effect, as a preference for FSP was only observed when acclimatised to FSP; when acclimatised to HDCIS there was no significant difference between FSP and HDCIS ratings. This suggests that the perceptual difference between the processing strategies is lessened when acclimatised to HDCIS. In other words, when acclimatised to FSP, the difference in the sound provided by the addition of low-frequency FS is more perceptible, and/or accessible to the user. When acclimatised to HDCIS, these same FS cues appear to provide less benefit for music appreciation.

It is of interest to note, though, that if a participant showed a significant strategy preference (i.e. CI2 and CI4) this preference did not switch when the acclimatisation strategy was changed. This could suggest that the acclimatisation phases may not have been long enough, or that the participant’s preferences existed irrespective of what they were acclimatised to. In other words, acclimatisation may have merely accentuated their preference. Galvin et al. (2009) found that training can improve melodic pitch perception, and suggested that some weak pitch cues may be available, but that CI recipients must be trained to use them. Similarly, it may be that there are FS cues within FSP that require a period of time for learning to utilise them, and if the participant is acclimatised to a different processing strategy, they are less able to utilise these FS cues.

The concept of acclimatisation, and controlling for it, appears to have received mixed attention in the literature. For CI studies which involved within-subject comparisons of speech processing strategies, some allowed for an acclimatisation period (e.g. Arnoldner, et al., 2007; Filipo, Ballantyne, Mancini, & D'elia, 2008; Firszt, Holden, Reeder, & Skinner, 2009; Kompis, Vischer, & Häusler, 1999; Zwolan, et al., 2005), others did not allow for acclimatisation (e.g. Kasturi & Loizou, 2007; Loizou, Stickney, Mishra, & Assmann, 2003; Milczynski, et al., 2009; Vandali, et al., 2005; Wilson, et al., 1991), and still others factored in a seemingly short 1-2 week acclimatisation period (e.g. Erdenebat, Kitazawa, & Iwasaki, 2004), or a 4-6 week period during which the speech processing strategy was continually re-programmed in order to optimise the parameters (e.g. Kiefer, Hohl, Stürzebecher, Pfennigdorff, & Gstöettner, 2001; Skinner, et al., 2002). Notably the majority of studies which compare speech processing strategies do not focus on the music perception abilities of participants or their ratings of the sound quality, but rather their speech perception abilities. In some of the studies which did not allow for acclimatisation, the results showed superior performance for the un-acclimatised strategy, warranting the question whether the performance of the participants would have been even better with acclimatisation (e.g. Wilson, et al., 1991). Therefore, the potential requirement of an acclimatisation period for many CI studies where participants were tested with multiple strategies or device settings needs to be accounted for when interpreting results.

In a recent study, objective measures of speech performance and subjective speech-sound quality were used to compare the FSP and CIS+ speech processing strategies (Vermeire, Kleine Punte, & Van de Heyning, 2009a). The authors found that when switched from CIS+ to FSP, the participant’s performance when listening to speech in noise initially deteriorated, but after 12 months of acclimatisation, performance with FSP was significantly better than the CIS+ measurement taken 12 months earlier. In contrast, when switched from FSP to CIS+, this pattern of results was not observed, as there was no initial deterioration of scores post switch-over. The authors suggested that a suitable acclimatisation period needs to be considered for FSP; however, the optimal length of time was unclear, and likely to vary depending on each individual. Similarly, Qi et al. (2009) found when assessing the speech perception abilities of Mandarin speaking MED-EL CI recipients, using an adapted 10-channel CIS strategy or FSP, an acclimatisation period longer than the 6 weeks in their study may have provided better outcomes, and when switched from one strategy to the other, there was an initial decrease in speech perception scores.

The overall groups' data in this study also demonstrates the impact which acclimatisation may have; when acclimatised to FSP, the group consistently preferred FSP, whereas when acclimatised to HDCIS, the group's preferences were mixed depending on each rating scale. It has been discussed in the literature that the preferences for speech processing strategies observed in within-subject comparative studies strongly favours the processing strategy that the participants have the greatest experience with (e.g. Dowell, Seligman, Blamey, & Clark, 1987; Tyler, Preece, & Lansing, 1986; Wilson, et al., 1991). Keeping in mind that all participants used FSP as their default strategy prior to the study, this study is consistent with these reports, showing that acclimatisation to FSP leads to a preference for FSP, whereas acclimatisation to HDCIS did not produce such clear preferences. This could possibly suggest that when acclimatised to HDCIS, the ability to perceive and utilise the FS cues available in FSP are lessened.

It therefore appears that acclimatisation to major changes in programmes are crucially important, and therefore any performance testing should not be carried out until a period of time has lapsed where the CI recipient can adjust to the new sound. If assessments are carried out without allowing for this period of acclimatisation, results may not demonstrate the true potential of the new programme. This is not discussed in a number of the studies mentioned above, and there is no way of knowing if their results may have been biased by not allowing for acclimatisation.

When describing the sound heard with each processing strategy, the averaged group data shows that the music generally did not sound as the participants wanted it to. The sound quality was consistently rated as emptier than the participants wanted it to sound, irrespective of which strategy they were acclimatised to; however, the mean ratings on the sharpness and roughness scales varied depending on which strategy the participants were acclimatised to, and which they were listening with. When comparing the two speech processing strategies, FSP was rated as closer to what the participants wanted it to sound like on the averaged-MPS, when acclimatised to FSP. For each individual MPS, HDCIS was rated similarly to FSP on the fullness scale (emptier than the participant would like it to sound), and sharper and rougher than FSP on the other two scales. Due to the tonotopic arrangement of the cochlea, and the inability to insert electrode arrays the full length of the cochlea, the low-frequency spiral ganglion cells at the apical end of the cochlea are not as effectively stimulated. Therefore, as a consequence, CIs have typically struggled to convey low-frequency place information to the user, which may be shown in this study with HDCIS sounding sharper and rougher than FSP. It appears that the low-frequency temporal FS encoded by FSP is perceived by the recipients as an improvement of the sound on the sharpness and roughness scales. For the pleasantness, naturalness, and richness scales, the averaged group data shows the trend of rating the acclimatised-to strategy to be more pleasant, natural, and rich, however, the differences were not statistically significant. Previous research has reported that CI recipients often describe music to sound scratchy, squeaky, tinny, booming, un-natural, mechanical, or noisy (Dorman, et al., 1991; Gfeller, 1998; Gfeller, et al., 2000a; Gfeller, et al., 1998; Looi & She, 2010), and generally report the sound quality to be poor. The results of this study are consistent with these findings, showing that the sound of music is not as the participants would like it to sound.

The descriptions of sound generally follow the results of Looi and She (2010), who found that CI recipients describe music to sound emptier, noisier, tinnier and rougher than what they expect it to sound. It should be noted, however, that one major difference between the Looi and She study and this research was the nature of the data collection. The Looi and She study used a questionnaire which asked the participants to recall how each genre sounded on a number of VAS rating scales; participants did not listen to actual music excerpts and rate them. In the current study, participants were presented with a specific set of songs to listen to and rate.

It therefore appears that the addition of low-frequency FS information by the addition of CSSS leads to a sound which is less sharp, less rough, and closer to what the participants would like it to sound, when compared to HDCIS. The fact that FSP was not found to be significantly different on the pleasantness, naturalness, richness, and fullness scales suggests that though the low-frequency FS may be perceivable, its addition may not yet be the answer to improving the perceived sound quality of CI users on these scales. It is still unclear at this stage how much FS information is perceivable by CI recipients, and to what extent FS will improve music quality; however, it is clear that the addition of FS will not make music sound 'perfect', as physiological and technological limitations still exist. This is supported by Swanson (2009), who found that an experimental processing strategy which used half-wave rectification to provide FS information did not improve the pitch perception abilities of Cochlear Nucleus CI users.

7.2.2 Hypothesis Three – Music Genre

This study showed that music genre has an effect on music quality ratings for some individuals; however, there was no overall consensus as to which genre(s) were 'the best', and no overall effect of genre for the averaged group data. Therefore the findings of this study do not support hypothesis three. One participant (CI1) rated classical music significantly higher than the other genres for all VAS, and showed some preference for the common over the country and western songs on the richness scale. Participants CI2 and CI4 showed a main effect of genre, however, post-hoc analysis did not show one genre to be rated significantly higher than the others, apart from CI4 rating the common songs closer to what they wanted them to sound like than the country and western songs on the averaged-MPS. Participants CI3 and CI5 showed no main effect for genre, as was the case for the averaged group data.

These results agree with those of Gfeller et al. (2003), who used two VAS rating scales for appraisal (like-dislike, and simple-complex). They found that their CI participants did not rate any one of the classical, country and western, and pop/rock genres higher than the others on the likeability scale. The authors postulated that this lack of difference between genres, in light of the fact that their NH participants showed a clear effect of genre on liking, could be due to the degraded representation of the music that the CI recipients received. In other words, the CI participants may have been unable to meaningfully differentiate between the three genres and, therefore, provided similar ratings for each. In contrast to some other studies, Arnoldner et al. (2007) found their participants scored 10%-points worse with FSP than CIS in detecting differences in non-rhythmic melodies (i.e. a pitch perception task). No explanation was provided by the authors as to why this may have been the case; however, this may have contributed to the lack of significant differences between genres in this study.

Looi and She (2010) in their questionnaire on music sound quality found that country and western music was rated as significantly more ‘pleasant’ than pop/rock, and significantly ‘more normal’ than classical items; the authors concluded that CI recipients tended to prefer country and western music. This was not shown in the data from this study; however, as discussed previously, the difference in methodologies between the Looi and She study and this research may possibly have contributed to this.

In this study, for the averaged group data, the order of ratings from highest to lowest on the pleasantness scale was common songs, followed by classical, country and western, and modern. Looi and She's (2010) participants found the order of pleasantness to be country and western (highest rated), classical (orchestral, small group or choir), jazz and lastly pop/rock. It is interesting to note that the order of preferences on the pleasantness scale was similar, especially with modern or pop/rock being the least pleasant sounding music.

Gfeller et al. (2003) looked at correlations between genre, song complexity, and likeability ratings, and found a strong negative relationship between liking and complexity ($r = -0.72$), showing that the CI participants liked more-simple songs. Although there were no statistically significant differences between complexity or likeability ratings for the genres used, the order of likeability from highest to lowest was country and western, pop, and classical, and for complexity the order from highest to lowest was classical, country and western and pop. Though perceived complexity was not measured in this study, it is worth noting that the common songs, which consisted of a single female singer and single instrument, were the least complex items in the MQRTB. The averaged group data showed that for the averaged-VAS, the common songs received the highest ratings followed by classical, country and western and modern, however, the differences between the ratings were not statistically significant. This trend appears to agree with the results of the Gfeller et al. study, where the least complex songs (i.e. the common songs) were rated the highest.

The favourite songs chosen by the participants (Appendix G) are worth commenting on. Firstly, with the exception of one participant (CI1), all songs contained prominent lyrics, which agree with previous research findings that lyrical content is used by CI recipients to recognise and appreciate music (Fujita & Ito, 1999; Gfeller, et al., 2008; Looi & She, 2010). Secondly, the tempo of all of the songs tended to be slow, which may be in keeping with the preference for less-complex music discussed above. Lastly, it appears from the dates of release that the favourite songs chosen by the participants in this study tended to be from the participants' adolescent or early adult years (i.e. the participants were less than 35 years old when these songs were released). Therefore, it is assumed that these songs were familiar to the participants prior to developing profound deafness.

In conclusion, it appears that genre on its own has little effect on the music quality ratings of CI participants, possibly due to the fact that the CI participants cannot sufficiently perceive the subtle stylistic differences between each genre. It is more likely that some degree of differences measured between genres in studies is due to differences in the complexity of the songs used. Therefore, it is possible that if similarly complex songs from different genres were used in a subjective music quality task, there would be little difference between the ratings given.

One interesting set of results worth highlighting are those of participant CI2, who was particularly adept at discerning which processing strategy she was listening to. She often commented, however, that the ability to tell the difference between FSP and HDCIS was much more difficult when listening to the classical pieces. This perceptual difference may be due to the spectral content of the songs, or to the type of instruments used in the pieces, which were string-based orchestras. To investigate this further, the SSD values for this participant, which were used to test for an acclimatisation effect (Section 6.2.2), were analysed further. Because the SSD is a measure of the distance between the participant's FSP and HDCIS ratings, it would be expected to show a smaller value for the classical items (i.e. the ratings are more similar) when compared to the other genres if the reports of this participant were correct.

Table 38 shows analyses using Wilcoxon signed ranks tests of the differences between the SSD values for classical versus modern, country and western and common genres. The results show that for the pleasantness, naturalness, richness, and fullness scales the participant consistently rates FSP and HDCIS closer together (i.e. a smaller SSD) for the classical items when compared to SSDs for the modern and country and western items. This means that for the classical items, the sound heard using FSP and HDCIS is less discernibly different. There are no significant differences between the SSD values for the classical and common songs, except on the fullness scale. This finding may also be related to the complexity issue discussed above. The complexity of the classical pieces may have meant that participant CI2 was less able to perceive or discern the low-frequency FS information available with the FSP strategy.

One possible explanation for this observations is that it appears in the literature that CI recipients find string instruments difficult to identify (Gfeller, et al., 1998), bowed string instruments (as used in the MQRTB items) the least pleasant of the string instruments (Schulz & Kerber, 1994), and classical ensembles to be less pleasant to listen to than single instruments or less complex genres (Gfeller, et al., 2003; Looi, et al., 2007). Another possible explanation for this could be that the low-frequency information within the classical songs may have been less prominent than in the other genres, due to the acoustic properties of the instruments used and the stylistic characteristics of this genre. In other words there may have been less low-frequency FS transmitted via CSSS to this participant.

Table 38: **Mean SSDs and standard deviations (in parentheses) for participant CI2, separated for each genre.** Mean ratings for each scale, averaged-VAS, and averaged-MPS are shown, with Wilcoxon test results comparing the means of the classical genre SSDs to the modern, country and western, and common genres' SSD values.

	Mean (SD) Session Strategy Difference (SSD) values				Results of Wilcoxon tests					
	Classical	Modern	Country and Western	Common	Classical vs Modern		Classical vs Country & Western		Classical vs Common	
					Z	p	Z	p	Z	p
Pleasantness	-1.02 (1.86)	2.21 (3.43)	3.44 (1.37)	1.26 (2.03)	-2.197	0.028*	-2.366	0.018*	-1.859	0.063
Naturalness	-0.83 (2.59)	2.12 (2.94)	3.04 (1.34)	1.34 (2.16)	-2.366	0.018*	-2.366	0.018*	-1.352	0.176
Richness	0.06 (2.38)	2.70 (2.50)	3.95 (1.47)	2.25 (2.63)	-2.028	0.043*	-2.366	0.018*	-1.352	0.176
Fullness	-0.28 (1.70)	2.53 (3.41)	2.65 (1.29)	2.64 (2.05)	-2.028	0.043*	-2.201	0.028*	-2.028	0.043*
Sharpness	-0.06 (1.96)	0.08 (3.46)	-2.08 (1.01)	-0.35 (1.76)	-0.169	0.866	-1.859	0.063	-0.507	0.612
Roughness	-0.41 (1.88)	-1.25 (1.70)	-1.34 (1.04)	-0.58 (2.54)	-1.183	0.237	-1.352	0.176	-0.507	0.612

* indicates those values which are significant ($p \leq 0.05$).

7.2.3 Hypothesis Four – Song Familiarity

The results of this study did not, in general, support hypothesis four, finding that song familiarity had little effect on music quality ratings. Song familiarity has been shown to improve music quality ratings for NH individuals (Gfeller, Asmus, & Eckert, 1991; Radocy & Boyle, 1988) and to a lesser extent for CI recipients (Gfeller, et al., 2003). However, very little research has been carried out on how familiarity with test items affects the music quality ratings given by CI recipients, and no research has investigated ratings for participants' favourite songs. In this study, although three participants' ratings for the familiar and obscure songs were significantly different from each other, the averaged group data did not show any differences between familiar and obscure songs. Participant CI1 rated the familiar songs more pleasant than the obscure songs, participant CI4 rated the familiar songs more pleasant, natural and rich than the obscure songs, and participant CI3 rated the obscure songs as more pleasant and natural than the familiar songs. For participants CI2 and CI5 no significant differences were observed between the familiar and obscure songs. The ratings for participants' favourite items were, in general, not significantly different to the familiar items, also suggesting that the degree of familiarity may not impact on music quality ratings.

Gfeller et al. (2003) studied the effect of song familiarity across the three genres of classical, country and western and pop, and found no overall effect of song familiarity on appraisal ratings; however, within this they found that familiar pop songs were rated higher in likeability and lower in complexity than obscure pop songs. In other words, in their study, song familiarity may have been related to genre and complexity (i.e. pop songs were less complex and more recognisable), which in turn had some relationship to appraisal ratings (as discussed in Section 7.2.2). The authors suggested that because there were more familiar items in the pop genre compared to the classical and country and western genres, the influence of familiarity was more pronounced in the pop genre.

In studies looking at song recognition, the most salient cues appear to be rhythm and the presence of lyrics (Gfeller, et al., 2005; Gfeller, et al., 2002a); however, CI recipients are less able to recognise familiar songs than NH individuals (Gfeller, et al., 2005; Gfeller, et al., 2002a; Stordahl, 2002). CI recipients tend to use prior knowledge of music (e.g. familiarity with a song) in order to make sense of the degraded or incomplete signal they receive (Gfeller, et al., 2003), and therefore an obscure song may be rated lower on appraisal tasks. In support of this hypothesis, Looi and She (2010) found in their questionnaire that a significant aspect which enhanced the enjoyment of CI recipients music listening experience was familiarity with a song (78% of respondents); however, there does not appear to be any studies in the literature that examine which aspects of sound quality are affected by song familiarity. Because real-world songs were used in the MQRTB, and an extensive selection process was carried out to ensure the high probability it contained familiar and obscure items, it was expected that the MQRTB would provide useful data to address whether familiarity affected music quality ratings.

Participant CI3 was the only participant who rated the obscure items significantly higher on the pleasantness, and naturalness scales, as well as the other scales (but not to a level of statistical significance). Lassaletta et al. (2007) found that 29% of CI recipients disagree or strongly disagree with the statement that 'music sounds like music', and as a consequence are often disappointed or frustrated with their music listening experiences. It may be in the case of participant CI3 that she had higher expectations of what the familiar songs should sound like, and when these expectations were not met, lower music quality ratings were given. In contrast she would have had fewer expectations for a song which she was not familiar with. Another possible explanation for the lower ratings given to the familiar items is that the participant may not have liked these songs, and therefore the ratings are a reflection of her opinion of the songs (i.e. likeability), which may not be similarly applied to the obscure items.

As a cross check of familiarity, when the participants heard each song for the first time, the test administrator informally asked if they knew the song and if they could name anything about it such as the title, composer or artist. All participants, with the exception of CI4 (who only recognised Twinkle Twinkle Little Star and Eine Kleine Nachmusik), knew all four of the familiar items, and were unsure, or did not know the four obscure items. As participant CI4 did not recognise all of the familiar songs, their data was removed from the averaged group data for familiar songs and re-analysed to ascertain whether this anomalous data had affected the overall group results. The results of this are shown below in Table 39, which show that there are still no significant differences between familiar and obscure songs for the averaged group data when the data for CI4 is removed. This finding should, however, be interpreted cautiously, as the group data is averaged from only four participants.

Table 39: Results of new analysis of the averaged group data (excluding participant CI4), for how song familiarity affects music quality ratings.
Mean ratings for the familiar and obscure songs for each rating scale, and the averaged-VAS and averaged-MPS are shown, along with the test statistics from a paired t-test . The degree of freedom equals 23 for all t-tests.

	Mean (SD) Familiar	Mean (SD) Obscure	Paired t-test	
			t	p
Pleasantness	5.07 (0.99)	4.95 (0.97)	0.54	0.592
Naturalness	4.53 (0.90)	4.76 (0.96)	-1.10	0.285
Richness	4.13 (0.72)	4.07 (0.94)	0.31	0.761
Averaged-VAS	4.58 (0.78)	4.59 (0.92)	-0.07	0.944
Fullness	2.81 (0.77)	3.03 (0.62)	-1.45	0.160
Sharpness	3.55 (0.79)	3.24 (0.79)	1.49	0.150
Roughness	3.98 (0.71)	3.99 (0.40)	-0.07	0.947
Averaged-MPS	3.45 (0.33)	3.42 (0.42)	0.27	0.786

When examining the data for familiarity, it is worth considering the potential of a learning effect throughout the study, whereby in the second and third testing sessions, the obscure songs were now familiar, and therefore the ratings may have been different to the obscure items from session one. Statistical analysis to investigate this was not possible, due to the small subject numbers and high inter-session variability between ratings for each participant. This variability would have masked any upwards or downwards trends in ratings due to obscure items becoming familiar. Previous research has, however, found that recognition of familiar melodies is particularly difficult for CI recipients (Gfeller, et al., 2003; Gfeller, et al., 2002a), and the ability to remember previously obscure melodies which the participants had been exposed to during testing was 5% above chance (Cooper, et al., 2008). In this study, by the third testing session, the participants would have only heard the obscure songs four times, and therefore, based on previous studies, it could be assumed unlikely that the participants recognised or remembered the songs from the previous testing sessions. Irrespectively, it must be reiterated that in this study, for the averaged group data, there was no significant difference between the ratings for familiar and obscure songs.

7.3 The MQRTB

The use of VAS to assess music quality, and the subsequent analysis of results has received considerable attention in the past. There is currently no consensus on a methodological standard for obtaining quality ratings for music (Gfeller, et al., 2003), with previous studies having used Likert-type scales, semantic differential scales (of which VAS are a subset), linear numerical scales (i.e. give a number from 1-10) or paired-comparisons, to investigate music preferences (De Vellis, 2003; Dunn-Rankin, 1983; Gfeller, et al., 2003).

The purposes of the scales in this study were to: (1) provide a mode for participants to indicate a preference along a scale anchored with two bipolar adjectives to act as clearly defined positive and negative end-points; (2) measure the extent of any preference; and (3) provide information on what it was about a sound which the participant did or did not like. Therefore VAS were considered more appropriate than Likert scales or paired-comparison tasks.

The design of the MQRTB rating scales and the use of a touchscreen monitor to make the ratings proved to be very successful. The participants quickly learnt to use the touchscreen, and did not find the task difficult, which may have allowed for more attention to be paid to the listening task, rather than on how to respond. The apparent ease of the task in this study is in conflict with evidence that the use of VAS in the elderly population is problematic (Williams, Oberst, Bjorklund, Kruse, & Coggon, 1988), which could be further complicated by a touchscreen which may be unfamiliar technology for this population. In a discussion of the strengths and limitations of VAS, Wewers and Lowe (1990) pointed out some difficulties in administering a paper-based VAS task, such as the parallax error of viewing the scales at an angle, the considerations of a person's eyesight and fine motor skills to make a precise mark, and the large amount of paper required to administer the task. In the case of this study, if the MQRTB was a paper based task using the same visual layout as the touchscreen format, the participants would have had to flick through 40 pages of rating scales for each session, making the task completion much more onerous. Coupled with this, the considerable time required to measure and record the position of the mark made by the participants on each VAS has been averted by the computer based MQRTB, which recorded and saved the marker positions as a tab delimited file. This, therefore, made the administration and recording of the data much more feasible, and removed the possibility of transcription errors. This is an especially pertinent point if this task is to be used in a clinical setting in the future.

The FSP versus HDCIS pilot study showed that the MQRTB could be effectively used for within-subject comparisons (e.g. comparing two different programme settings); however, there is no reason that the MQRTB couldn't be applied for between-subject or between-group comparisons provided there are sufficient participant numbers. VAS are prone to high variability within participants, with reports of test-retest correlations between ratings of the same concept made over several days varying from 0.19 to 0.90 (Folstein & Luria, 1973), and large intra-subject variability. When examining the data in this study, it is evident that there was significant inter-session variability between the ratings given by the participants. In an attempt to account for this the relative difference between the ratings was analysed (i.e. the SSD). It has proven difficult with the small numbers of participants to determine the source of the variability. Factors to consider include the dependent variables themselves, other extraneous factors, participant-specific factors such as the number of channels of FSP stimulation, the number of switched on electrodes, or factors such as attention, or learning of the task. Therefore, in light of this, the application of the MQRTB for within-group comparisons with small numbers of participants is challenging; however, the potential for the MQRTB to be used in this manner with larger groups cannot be discounted.

In this study, the scales and their accompanying descriptive adjectives, were selected from common descriptors identified in previous research on musical and timbral descriptors of sound, with a focus on those specific to CI recipients (1991; Gfeller, et al., 2002c; Looi, et al., 2007; Looi & She, 2010; von Bismark, 1974a, 1974b). Wewers and Lowe (1990) discussed the difference between a unipolar and bipolar VAS and the requirement for very careful selection of the descriptive adjectives, especially for bipolar VAS. Unipolar VAS use descriptors that are direct opposites of each other (e.g. unpleasant-pleasant), whereas bipolar scales use terms which assume the participant interprets these terms as opposites, but there is a possibility of this not being the case (e.g. tinny-rich). In this study, the first three scales (unpleasant-pleasant, unnatural-natural, and tinny-rich) were true VAS, and in the case of the first two, the adjectives are unipolar. The tinny-rich scale is bipolar, as the descriptors could be interpreted differently by the participants based on their internal mental representation of what the terms tinny and rich mean. In other words a participant may not consider the opposite of tinny to be rich, but rather another concept such as ‘boomy’ or ‘dull’. Based on this argument Wewers and Lowe (1990) propose that unipolar adjectives are better suited to VAS, and bipolar adjectives should only be used when the descriptors are direct opposites, and clearly defined for the participants. The second three scales used in the MQRTB are also bipolar variations of VAS (emptier-fuller, duller-sharper, and smoother-rougher), and therefore the same argument against their use could be applied as to the tinny-rich scale. They were further complicated by the midpoint labelled 'exactly as I want it to sound', which in effect separated the scale into two distinct halves. This is of no consequence if the participant interprets the descriptors as opposites to each other, however, if this is not the case they will only use one half of the scale to make their ratings because the other half of the scale to them is a different perceptual concept. This may have been the case for participant CI4, who only rated on the left-half of the second three VAS for the entire study. Future improvement of the MQRTB may be to alter the descriptors to retain the perceptual attributes of pleasantness, naturalness, richness, fullness, sharpness, and roughness, but adapt the descriptors for the scales to become unipolar in nature. For example the descriptors could be changed to unpleasant-pleasant, unnatural-natural, not rich-very rich, not full enough-too full, not sharp enough-too sharp, not rough enough-too rough[7]. Previous music or instrument sound quality studies have contained a mixture of unipolar and bipolar VAS (e.g. Gfeller, et al., 2003; Gfeller, et al., 1998; Looi & She, 2010), therefore there does not seem to be a consensus among CI researchers whether unipolar or bipolar VAS provide more reliable results when assessing the sound heard through a CI.

Another potential problem with the scales used has been the nature of how the participants used them, and whether biases often observed in other studies using rating scales have been introduced in the responses in this study. Some common types of bias that can occur in data collection can include a central tendency bias (i.e. rating only on the middle section of the scale), an extreme bias (i.e. rating only at the extreme ends), and a socially desirable bias (i.e. a tendency to rate according to what

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[7] Remembering the fullness, sharpness, and roughness scales have a midpoint descriptor "exactly as I want it to sound".

the participant thinks the examiner would like) (Cronbach, 1946, 1950). The halo effect (Thorndike, 1920), which is the tendency for previous ratings to affect subsequent ratings, could also occur. In the context of this study it may be that the participant sees that FSP is the most recent technological advance for MED-EL recipients, and subsequently believes that it must be better. This concept was also discussed by Looi et al. (2007) in relation to music perception studies with CI recipients. The current study aimed to address this by blinding the participants to the strategy which they were using at the time of making their ratings, however, for some participants (e.g. CI2) the perceptual difference between the strategies was clearly evident, and therefore they often knew which strategy they were listening to.

The finding in this study of no significant differences between the participants' favourite songs and the familiar songs suggests that future use of the MQRTB may not need to include two of the participant's own songs, should time or logistics be of concern. This would reduce the number of songs and therefore presumably the testing time by 20%. No studies in the literature have measured whether the degree of familiarity with a song effects the music quality ratings, however, Gfeller et al. (2003) did suggest that higher ratings for the pop songs in their study may be due to the participants being 'more-familiar' with the pop items than the classical and country and western items. The results of this study do not support this inference, and it may be that the differences observed by Gfeller et al. are due to other factors such as song complexity (as discussed in Section 7.2.3).

7.4 General Discussion

Speech perception results from the participants were widely varied, consistent with reports in the CI literature of significant intra-subject variability (Wilson, 2004). Participant CI4 scored the lowest of the group, possibly attributable to the fact that she only had a partial electrode array insertion and consequently had five channels switched off. It should be noted that due to inclusion of NZ and Australian participants in the study, different word tests were used for each country; the last three participants were tested with the Australian CNC word lists, and the first two a NZ version of the CNC word lists. There could, therefore, be different levels of difficulty between these tests, which may have led to the differences in the phonemes and words correct scores. There is no published research comparing the performance or difficulty levels of these test materials. The sentences tested in quiet and noise may in one respect, hold more face validity, as the stimuli used were the same for all subjects; however, it may also be that they were biased to the Australian participants as the recordings were made by an Australian speaker with an Australian accent. Correlations with music quality ratings were not carried out due to the small subject numbers, but would be an interesting investigation for a future study.

The lack of subject numbers also prevented statistical analysis for differences between strategies or listening conditions (i.e. quiet versus noise). The general trends of the average speech perception scores suggest little difference in performance between listening with FSP and HDCIS, with the exception of the sentences in noise results. These show the mean FSP score to be much larger than the mean HDCIS score, and could possibly be illustrating the benefit of providing low-frequency FS information. This observation agrees with Arnoldner et al. (2007), who directly compared the performance of FSP to CIS on speech perception tests in quiet and noise, along with some music perception tasks. They found that after 12 weeks, the performance of their participants with FSP was significantly better than with CIS when listening to speech in noise. Smith, Delgutte, and Oxenham (2002) and Friesen et al. (2001), found that FS is required for sound localisation and listening in noisy situations, therefore these results may be reflecting the advantage of FSP over HDCIS in discriminating speech amongst noise. It is also worth noting that the ability to perceive sentences in noise is closely related to pitch perception (Smith, et al., 2002); in other words the elements required for speech perception in noise are also required for pitch perception, and therefore relevant to the findings of this study.

One observation worth noting is with regards to participant CI2 who was a 'star performer'. As mentioned previously, this participant was able to discern which processing strategy she was listening to, and displayed a very clear preference to FSP irrespective of which strategy she was acclimatised to. This participant was the only one in the study who was stimulated with two FSP channels. Therefore it may be that the number of channels of FSP stimulation correlates with the ability to discern between FSP and HDCIS, and/or the ability to benefit from the FS information. More FSP channels should theoretically provide more FS information to the recipient. This is a tentative conclusion, however, as there were no other participants with more than one FSP channel. In a recent presentation by Krenmayr, Schatzer, Kals, Gründhammer and Zierhofer (2009a), a 10-channel version of the CIS strategy was compared to two different adapted FSP strategies, which had up to four FSP channels. The authors found that the FSP strategies were more effective than CIS at encoding the F0 of both unresolved and resolved harmonics for male and female voices. This study suggests that at least four FSP channels are possible in a FSP programme, and this appears to provide information that will be beneficial to music appreciation. It should also be noted that participant CI2 had extensive pre-deafness music experience, was still interested in music post-implant, and was heavily involved in the habilitation of other adult CI recipients. Therefore her ability to discern between FSP and HDCIS may not be solely due to the number of channels of FSP stimulation, but as a consequence of extensive experience and focused analysis of her listening experiences.

It is interesting to observe that the two participants who showed some preference for HDCIS were those with partial insertions. Participant CI4 showed a clear HDCIS preference and participant CI5 a partial preference, depending on which sound-attribute was being assessed. In particular, participant CI4 felt that when listening with HDCIS, speech was easier to understand, especially in noisy situations, although there was no clear advantage shown in speech testing results. This may imply that as the number of available electrode pairs for stimulation decreases from the maximum of 12, the usefulness of the FSP channel(s) decreases. One suggestion is that for partial insertions, the addition of an FSP channel not only provides a different type of information, but also decreases the number of available HDCIS channels. Hence the filterbank spacing for these higher frequency channels becomes wider, thereby increasing the potential of spectral smearing and/or multiple harmonics falling in the same filter (Looi, et al., 2008b). Another possible explanation relates to the perception of rate pitch on a tonotopic location in the cochlea which does not match the rate pitch's frequency. Oxenham, Bernstein, and Penagos (2004) found that temporal pitch information is best perceived if presented to tonotopic locations consistent with the respective place pitch frequencies. For example, a 300 pps rate pitch should be stimulated at the 300 Hz place on the BM. This is further confirmed by Vermeire et al. (2009b)who found when using FSP that that to get the best benefit from FS stimulation, CSSS pulses need to be presented at the corresponding tonotopic place on the BM. For a partial insertion, this is not possible, as the most-apical electrodes are not inserted far enough towards the apex, and as a result the low-frequency FS is presented at a higher-frequency place on the cochlea. It has been shown that the auditory system is able to adapt to a place-frequency mismatch (Svirsky, et al., 2004); however, it has also been shown that these mismatches decrease performance in both speech and music perception (Fu & Shannon, 2002; Kong, et al., 2004; Looi, et al., 2008b; Moore & Carlyon, 2005; Oxenham, et al., 2004). For partial insertions, it may be that compensation is more difficult due to a greater degree of frequency mismatch. The observation in this study of decreased preferences for FSP for the participants with partial insertions, could therefore suggest that for these recipients a trial of HDCIS may be warranted; particularly if results with FSP are not as expected.

One other aspect of the study is that the MQRTB only looked at subjective quality ratings, and not perceptual accuracy of the participants with music stimuli. Perception and appreciation are two separate issues in CI music research, and this study only focused on appreciation. Preliminary results on the accuracy of MED-EL CI users' perception of music with FSP have been provided by Arnoldner et al. (2007), Mitterbacher et al. (2005a; 2005b), and Krenmayr et al. (2009b).

7.5 Clinical Implications

This study has shown the MQRTB to be an effective tool for within-subject comparisons of music quality, and that it could be applied clinically to compare different speech processing strategies, programme settings, or listening modes for the same recipient. It provides enough data points to give detailed information on the ratings for specific timbral elements of music. Its use for between-subject or between-group comparisons is not able to be determined from this study due to the lack of participant numbers, and the degree of variability between the five participants involved. Future research with larger numbers should be conducted to assess both the test-retest reliability, and its sensitivity for assessing between-subject/group differences.

There is some preliminary indication that the number of FSP channels may correlate with the ability of individuals to appreciate music, as the only participant with two FSP channels in this study was observed to better differentiate between FSP and HDCIS, as well as better appreciate FSP over HDCIS. At present, the allocation of FSP channels in a programme is determined by the programming software and is determined by the measured Impedance and Field Telemetry (IFT) values. The larger the measured electrode impedances, the fewer FSP channels are allowed. Due to the potential benefits of having more than one FSP channel, it seems prudent that all attempts should be made by the manufacturers and audiologists to maximise this number, as it is clear that the transmission of FS leads to a more-natural sound perception (Riss, et al., 2009). Whether this means revising the criteria that the programming software uses to allocate the number of FSP channels, or changing parameters such as pulse width or rate, this would be a topic for further investigation. These suggestions are cursory, and are areas that the manufacturer is currently researching. Riss et al. (2008), when comparing speech perception with FSP and CIS, similarly suggested that increasing the number of FSP channels warrants further investigation. As pointed out before, increasing the number of FSP channels results in a decrease in the number of HDCIS channels. This could, therefore, result in wider filter bandwidths to cover the frequency range, and thus result in increased spectral smearing or decreased frequency resolution. Further to this, increasing the number of FSP channels would presumably require an increase in the upper boundary of the low-pass filter, which is currently set at 350 Hz for the CSSS pulse generation. The rationale for this limit is based on agreement in the literature that CI recipients are typically unable to perceive FS temporal pitch information greater than around this rate. In a recent study on the limits of temporal pitch perception in MED-EL CI recipients by Kong et al. (2009), the authors found that some of their participants were able to perceive temporal pitch at higher rates than expected, in some cases up to 500 Hz, and in their discussion identified a number of studies where individual participants showed similar results. Therefore, the 350 Hz limit currently set in the programming software may warrant extending for some recipients, with the assumption that this will facilitate an increase in the possible number of FSP channels, and this may be perceivable. In support of this, preliminary results of a pitch perception task using 4 FSP channels with a higher CSSS frequency range (100 Hz – 811 Hz) have shown an increase in pitch perception abilities when compared to using 10 channels of CIS stimulation (Krenmayr, et al., 2009b). This suggests increasing the number of FSP channels, and extending the frequency range for CSSS analysis is possible, subsequently improving the potential for better sound quality.

The need for an extended period of time to acclimatise to FSP may have implications in the functional testing of changes to programmes. Currently, speech perception assessments are used to determine the success of implantation, to track improvements in the user's performance, as well as evaluate the benefits of newer device settings, or program parameters. As there is the possibility that a CI user may not have fully acclimatised to a new programme before such testing is carried out, the purpose of speech testing needs to be considered by the audiologist, and timed appropriately in order to give a true representation of the abilities of the CI user.

There have been some suggestions in the literature that specific programmes for music listening could be set up in the speech processor, much the same as HA users are able to switch to a different program (e.g. Kasturi & Loizou, 2007). Based on the observations in this study, this may not be practical for many recipients, due to the time required for acclimatisation. It may be that the recipient needs to use this 'music programme' for some period of time before being able to realise the benefits it may provide. Regardless of acclimatisation, a music programme with alternative filterband spacing (as discussed in Kasturi & Loizou, 2007) and/or enhanced FS information may provide a more-preferable music sound, and therefore, could be an area for further investigation.

There is some evidence in this study that individuals with partial insertions of the electrode array may find the sound of music with FSP (and possibly speech) less pleasant than HDCIS. Therefore, it may be of benefit for them to undergo a trial period, where after the patient acclimatises to each strategy, a sound quality rating task could be conducted to compare the outcomes. Provided that there is little difference in speech perception between the strategies, the results of the trial would provide further information to optimise the listening experience for the CI user. There do not appear to be any studies of FSP in the literature which include subjects with partial insertions, therefore this discussion is limited to the observations from this study. It still seems preferable, however, to switch the individual on with FSP; as

Vermeire et al. (2009b) found, changing from FSP to CIS+ requires less acclimatisation than from CIS+ to FSP.

As it is commonly reported in the CI literature that music does not sound like CI users want it to, which is in agreement with this study, it is imperative that potential recipients be counselled about this. Preparing these recipients pre-surgery about the potential for music to sound unsatisfactory, pointing out that it may take some time to get used to how music sounds, and/or that focused listening practice would probably be required for improved music perception is important to ensure realistic expectations.

Current clinical protocol is to switch on new MED-EL CI recipients with FSP. The results of this study support this protocol, as it appears that acclimatisation to FSP takes an extended time period, but once acclimatised, recipients preferred the sound of FSP over HDCIS, even when acclimatised to the latter. In other words, the participants in this study tended to prefer FSP, once acclimatised to it, however, when acclimatised to HDCIS, their preference did not switch to HDCIS.

7.6 Limitations

The major limitation of this study was the low number of participants, due to factors beyond the researcher’s control. The number of participants was well below those anticipated, and as a result, the statistical power of the analyses was low. The large variability in participant characteristics further exacerbated the variability inherent to CI testing; with a larger number of participants, the individual variations in participant characteristics would have been better averaged across the group. Further, the lack of participants prevented the calculation of correlations to assess for relationships between different participant and test factors, as well as between strategy comparisons of FSP versus HDCIS results for some measures, such as speech perception.

Another area of concern for the researcher was that there was no way to ensure that the participant used the allocated processing strategy exclusively during the acclimatisation period. For example, if the participant did not like the sound of the processing strategy they were asked to acclimatise to, they may have used it intermittently, or not at all, and may therefore not have been sufficiently acclimatised to the strategy. Participants were asked to confirm that they used the allocated strategy as their default listening program for the preceding three weeks. However, as the speech processor does not have the ability to record hours of use for each programme or whether the participant has switched between programmes, there was no way of verifying this.

As the study found acclimatisation to a processing strategy had an effect on the music quality ratings, with Vermeire et al. (2009b) and Qi et al. (2009) also finding that FSP requires an extended period of acclimatisation, there is the chance that the three week acclimatisation phase in this study was not of sufficient time for the participants to be able to obtain maximal benefit from each strategy. Due to the time constraints of this study, this acclimatisation period could not be extended.

The considerations associated with the MQRTB, its limitations, and suggested improvements for the rating scales used have been discussed previously in Section 7.3.

7.7 Future Research

Now that the MQRTB has been pilot tested and found to be an effective tool for assessing within-subject music quality ratings, a larger scale study is required to assess its test/retest reliability, and capacity to compare between groups. For example, this could involve a repeat of this study (FSP versus HDCIS) involving more participants, a comparison of Electric-Acoustic Stimulation (EAS) versus electric hearing, a comparison between different technologies, or in non-CI based studies of music appreciation.

The benefit of a dedicated music training programme should also be evaluated (Galvin, et al., 2009). Incidental exposure to music does not produce significant improvements in music perception or enjoyment (Gfeller, et al., 2008), with research indicating that focused music listening and training can help to remediate some aspects of music listening (Cooper, et al., 2008; Galvin, et al., 2007; Galvin, et al., 2008; Gfeller, et al., 2002b; Spitzer, et al., 2008). It may be that a training program could assist CI recipients to better acclimatise to FSP, and/or effectively use the FS cues available when listening to music.

As mentioned, the optimal number of FSP channels in an FSP programme may warrant further investigation. Krenmayr et al. (2009a) showed that at least four FSP channels are possible, and this study indicates that increasing the number of channels of FSP stimulation may be beneficial for listening to music. Further investigation into what the optimal number of FSP channels is, and whether there is a limit to the number of FSP channels before it is detrimental to the perception and/or appraisal of both speech and music, may be warranted.

Further investigations of programme settings for CI recipients with poor outcomes or partial electrode insertions may also be warranted. In other words, do poorer performing CI recipients, or those with fewer available channels, require different programme or processing strategy settings in order to optimise their outcomes?

The current version of the MQRTB was specifically designed for the Australian and NZ population. Therefore its suitability and use in other countries could also be investigated. For example, the pieces in the 'common' genre, and 'familiar' and 'obscure' songs categories would need reconsideration.

7.8 Summary and Conclusions

A MQRTB was developed to assess the perceived quality of 'real-world' music items, while investigating whether song familiarity and genre had an effect on quality ratings. Initial testing on 67 self-reported NH and four CI recipients found the MQRTB to be of suitable length and complexity. The MQRTB was subsequently pilot tested by comparing the music quality heard with FSP and HDCIS for five MED-EL CI recipients. It was found to be a suitable measure of within-subject comparisons of different programme settings; however, due to low participant numbers it is unclear whether the MQRTB is suitable for between-subject or between-group comparisons.

Acclimatisation to FSP was found to affect the music quality ratings provided by the participants, who as a group, showed a preference to listening to music with FSP, when acclimatised to FSP. When acclimatised to HDCIS there were no significant differences between ratings with FSP and HDCIS. Generally, FSP was rated by the participants as closer to 'exactly as I want it to sound' than HDCIS; however the quality of music with FSP was still not 'exactly as I want it to sound' for the participants.

Song familiarity was found to have an effect on music quality ratings for some participants, but not for the overall averaged group data. For the participants who showed some effect of familiarity, two preferred the familiar songs, and one preferred the obscure songs. There was no difference between ratings for the familiar songs and the participant's favourite songs, therefore, the level of familiarity does not appear to have an effect on music quality ratings.

Overall, no one particular genre was rated significantly better than another genre for the averaged group data. Overall ratings on the pleasantness scale were highest for the common genre, followed by the classical, country and western, and modern genres, but there was a great deal of participant variability, and the differences were not at the level of statistical significance across the four genres.

Fine Structure Processing appears to provide more information to CI users that improves sound quality ratings, and there is some indication from this, and other studies, that more FSP channels leads to better performance on music appraisal and perception tasks. In contrast, the use of FSP with partially inserted electrode arrays and/or few channels for stimulation may not provide the best sound quality, and alternative options may warrant further investigation.

Cochlear implants have proven to be a very successful method of improving the quality of life of individuals with severe to profound hearing impairments. Although the sound of music is typically reported to be disappointing, it appears that FSP improves the sound quality of music over the previous HDCIS technology. Continued research into how to better convey the important FS features of music without affecting the speech perception abilities of CI recipients, is worthy of continued research.

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APPENDIX A: Selection Criteria for Phase One of the MQRTB Development

A.1 Inclusion Criteria

To develop an inclusion criteria the historical music chart history for NZ (Scapolo, 2007) and Australia (Kent, 2007) was extensively referred to. The inclusion criteria for the MQRTB pieces were:

Familiar Songs

Modern: The song (1) appeared in the top 20 of the annual singles chart for the year of release, in both NZ and Australia (2) has been included in at least 2 albums (i.e. in 'best of' or compilation, as well as original release album); (3) was one of the top 3 songs of a particular artist; (4) was released prior to 1980 (to increase the likelihood of the song being known to a larger age range); (5) has the most well-known portion of the song close to the start, to allow more time-efficient testing.

Common: The items were rated highly in both Looi et. al. (2003) and Jakody (unpublished) studies of familiar melodies.

Classical: The song (1) does not contain lyrics; (2) was identified in internet searches of the most commonly known classical pieces.

Country and Western: The song (1) appears on a 'best of' album; (2) appears on the top 100 annual singles charts in NZ and Australia; (3) was listed in the top 500 country music songs on the popular country music website: http://countrymusic.about.com/library/top500/bltop500.htm.

Obscure Songs

For all styles, the song must: (1) not have appeared in the top 100 annual charts for either NZ or Australia; (2) not appear in the artist summaries of released songs in either NZ or Australia; and (3) sound similar to one of the 'known' songs selected.

In order to source obscure 'common' songs, a number of 'common' children's songs from non-English cultures were obtained.

A.2 Pairing of Test Items

Each familiar song was paired with an obscure song with similar musical characteristics. This pairing was undertaken to provide a more objective assessment on the impact of familiarity on sound quality ratings, by reducing the musical differences between the two items.

The obscure songs were paired to the familiar songs on the following criteria: (1) Singer (i.e. male/female, solo/duet); (2) Band type (i.e. 3 piece, orchestra, dominant instrument); (3) similar rhythm and tempo; (4) if possible the same artist (in order to retain singer and style similarity); (5) similar spectral properties of piece (i.e. similar 'sound'); (6) same language used in lyrics (except for the common songs category)

A.3 General Considerations

In addition to the above-mentioned factors, there were other general considerations accounted for in selecting the MQRTB items. The musical 'sound' of the artists was considered to be an important aspect, as well as the ability to pair to similar sounding obscure items. Therefore, artists with a unique style or sound (e.g. Bee Gees, ABBA) were not considered for the study as it was felt they were not representative of the typical musical style. It was also difficult to source obscure songs by these artists to pair with the familiar equivalents.

The music chart history has only been available from 1966 to the present for New Zealand, and 1940 to the present for Australia. Therefore, although though there are well known artists or songs (e.g. The Beatles, Elvis Presley) that could have been included in the MQRTB, many were recorded prior to 1966 making it difficult to justify their selection based on chart positions. Consequently songs released prior to 1966 were not considered for the MQRTB.

APPENDIX B: Songs Selected for Phase One of the MQRTB Development

Table 40: Songs selected for phase one of the MQRTB verification.

Genre	Familiar		Album			Obscure		Album		
	Track Name	*Track no.*	*Album Title*	*Artist/ Composer*	*Distributor*	*Track Name*	*Track no.*	*Album Title*	*Artist/ Composer*	*Distributor*
Classical (no vocals)	Serenade ‘Eine kleine Nachtmusik, K525, 1st movement	6	Mozart - Musical Masterpieces, 2005	Mozart	Delta Music plc (by licence to International masters publishers, Montoursville, Pennsylvania)	Concerto in D major K.218 -Allegro.	4	Mozart 3 Violin Concertos – The English Concert, 2006	Andrew Manze	Harmonia mundi USA
	Brahms, Lullaby	1	Music for dreaming, 2001	Melbourne Symphony Orchestra	Sound Impressions Pty Ltd.	Hush-a-Bye Baby	3	Music for dreaming, 2001	Melbourne Symphony Orchestra	Sound Impressions Pty Ltd.
	Concerto for Violin in E major ‘Spring’ 1. Allegro	1	A Vivaldi Weekend, 1981	Vivaldi/ London Symphony Orchestra	Deutsche Grammophon GmbH, Hamburg	Vivaldi, Concerto for 4 violins and violin cello in B minor 1. Allegro section	13	A Vivaldi Weekend, 1990	Vivaldi/ London Symphony Orchestra	Deutsche Grammophon GmbH, Hamburg
Modern (male vocalist)	American Pie	1	American Pie: Original Recording Remastered, 2003	Don Mclean	Capitol records,	Everybody Loves Me	7	American Pie: Original Recording Remastered, 2003	Don Mclean	Capitol records,
	Candle in the wind* (1997)	12	Love Songs, 2001	Elton John	Island	Take Me Away	1	Through the Rain, 1999	Colliding Traits	Colliding Traits, Auckland
	Raindrops keep falling on my head	11	BJ Thomas All the hits: the ultimate collection, 1999	BJ Thomas	BMG International	Long Ago Tomorrow, by BJ Thomas	17	BJ Thomas All the hits: the ultimate collection, 1999	BJ Thomas	BMG International,

* This song was a re-release of the 1973 song ‘Candle in the Wind’ by the same artist.

	Familiar		**Album**			**Obscure**		**Album**		
Genre	*Track Name*	*Track no.*	*Album Title*	*Artist/ Composer*	*Distributor*	*Track Name*	*Track no.*	*Album Title*	*Artist/ Composer*	*Distributor*
Common song (female vocalist)	Baa Baa Black Sheep	33	Ultimate 100 Kids Songs, 2008	Juice Music	ABC Music, Sydney	Ithi Chaphachapa	3	Lize Beekman Lullabies, 2006	Lize Beekman	Bowline Musiek, Cape Town
	Old McDonald	21	Ultimate 100 Kids Songs, 2008	Juice Music	ABC Music, Sydney	Dorstyd	21	Carike in Kinderland, 2001	Carike	BMG Records Africa (Pty), Johannesburg
	Twinkle twinkle little star	37	Ultimate 100 Kids Songs, 2008	Juice Music	ABC Music, Sydney	Chu Ech On	21	Multicultural Rhythm Stick Fun, 1992	Georgiana Stewart	Kimbo Educational, Long Branch, NJ
Country & Western (male vocalist)	Achy breaky heart	1	Achy Breaky heart (Import), 2002	Billy Ray Cyrus	Polygram	Deja Blue	7	Achy Breaky heart (Import), 2002	Billy Ray Cyrus	Polygram
	Rhinestone cowboy	1	Glen Campbell, Greatest Hits, 2003	Glen Campbell	EMI Records NZ, Auckland	Do You Believe? (Dark Horizons)	9	Zodiac, 2008	Barry Saunders	Mana Music (NZ) Ltd, Auckland
	Country Roads take me home	3	John Denver, Greatest Hits, 2001	John Denver	BMG NZ, Auckland	Early Morning Rain	2	The Nashville Acoustic Sessions, 2004	Raul Malo, Pat Flynn, Rob Ickes, Dave Pomeroy	CMH Records, Inc., Los Angeles.

APPENDIX C: Song Familiarity Questionnaire

SUBJECT INFORMATION

Gender: male / female (Circle One) Age: ………………

Ethnicity: ………………………………… Country of Birth: ……………………………

1st Language: ………………………… Other languages spoken: ………………

How long have you lived in New Zealand? ………….. years

EMPLOYMENT DETAILS

☐ Full Time ☐ Student ☐ Unemployed

☐ Part Time ☐ Retired

Occupation (if retired, please state your previous occupation):

……………………………………………………………………………………………………

MUSICAL EXPERIENCE, LISTENING HABITS, & KNOWLEDGE

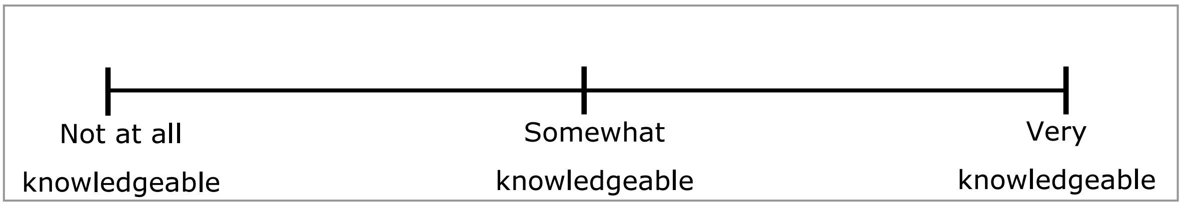
a) Tick as many options as necessary which describe the music genre(s) you most commonly listen to:

☐ Pop
☐ Rock
☐ Country and Western
☐ Other (Please specify) ……………………………………
☐ I do not listen to music regularly.
☐ Classical
☐ Jazz
☐ Folk

b) How often do you choose to listen to music?

☐ Never ☐ Occasionally ☐ Sometimes ☐ Often ☐ Very Often

c) Mark on the scale below where you feel your level of musical knowledge lies?



TASK INSTRUCTIONS

Please listen to the tracks on the accompanying CD and indicate on this response sheet how familiar each song is to you, using the descriptors provided.

You are NOT being tested on your musical knowledge; the task is assessing how familiar these songs are to New Zealanders, therefore I am after your initial response while listening to the song.

It is important that you do not 'go away' and try to remember the song's details or try to find out further information.

RESPONSE SHEET

Track	**I definitely know this song**	**I definitely do not know this song**	**I may have heard this song before, but I am unsure**	**What style of music do you consider this to be?**	**Please provide information you can about the song. (e.g. song title, composer or artist, or any information you can recall about the song, its context etc.)**
1	☐	☐	☐		Title: Artist/Composer: Other:
2	☐	☐	☐		Title: Artist/Composer: Other:
3	☐	☐	☐		Title: Artist/Composer: Other:
4	☐	☐	☐		Title: Artist/Composer: Other:
5	☐	☐	☐		Title: Artist/Composer: Other:
6	☐	☐	☐		Title: Artist/Composer: Other:
7	☐	☐	☐		Title: Artist/Composer: Other:
8	☐	☐	☐		Title: Artist/Composer: Other:

	Know	Do not know	May know	Style	
9	☐	☐	☐		Title: Artist/Composer: Other:
10	☐	☐	☐		Title: Artist/Composer: Other:
11	☐	☐	☐		Title: Artist/Composer: Other:
12	☐	☐	☐		Title: Artist/Composer: Other:
13	☐	☐	☐		Title: Artist/Composer: Other:
14	☐	☐	☐		Title: Artist/Composer: Other:
15	☐	☐	☐		Title: Artist/Composer: Other:
16	☐	☐	☐		Title: Artist/Composer: Other:
17	☐	☐	☐		Title: Artist/Composer: Other:
18	☐	☐	☐		Title: Artist/Composer: Other:
19	☐	☐	☐		Title: Artist/Composer: Other:
20	☐	☐	☐		Title: Artist/Composer: Other:
21	☐	☐	☐		Title: Artist/Composer: Other:
22	☐	☐	☐		Title: Artist/Composer: Other:
23	☐	☐	☐		Title: Artist/Composer: Other:
24	☐	☐	☐		Title: Artist/Composer: Other:

APPENDIX D: Final Songs Selected for the MQRTB

Table 41: Final songs selected for the MQRTB

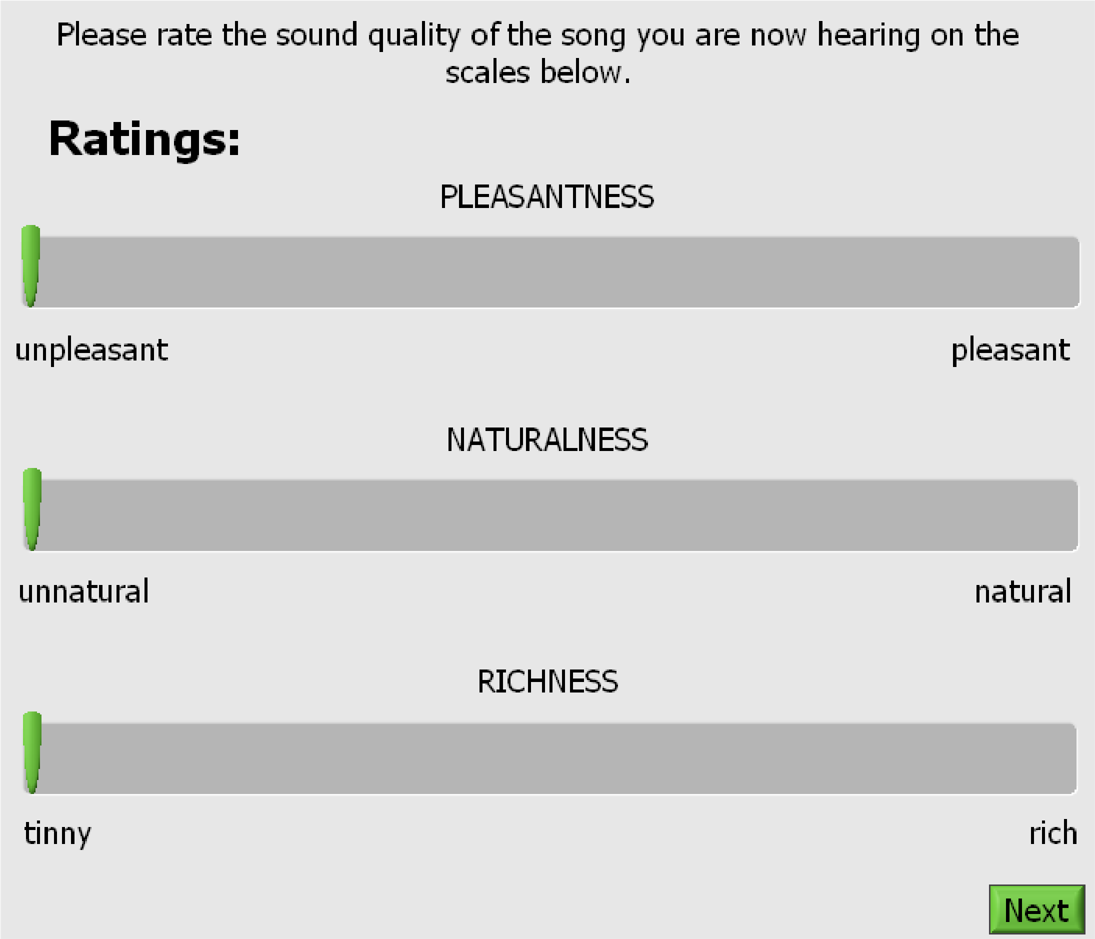
		Song Title	Album	Artist	Distributor
Familiar	Modern	Raindrops keep falling on my head	BJ Thomas All the hits: the ultimate collection, 1999	BJ Thomas	BMG International
	Classical	Serenade 'Eine kleine Nachtmusik, K525, 1st movement	Mozart - Musical Masterpieces, 2005	Mozart	Delta Music plc (by licence to International masters publishers, Montoursville, Pennsylvania)
	Country and Western	Rhinestone Cowboy	Glen Campbell, Greatest Hits, 2003	Glen Campbell	EMI Records NZ, Auckland
	Common	Twinkle Twinkle	Ultimate 100 Kids Songs, 2008	Juice Music	ABC Music, Sydney
Obscure	Modern	Long Ago Tomorrow, by BJ Thomas	BJ Thomas All the hits: the ultimate collection, 1999	BJ Thomas	BMG International
	Classical	Concerto in D major K.218 -Allegro.	Mozart 3 Violin Concertos – The English Concert, 2006	Andrew Manze	Harmonia mundi USA
	Country and Western	Do You Believe? (Dark Horizons)	Zodiac, 2008	Barry Saunders	Mana Music (NZ) Ltd, Auckland
	Common	Chu Ech On	Multicultural Rhythm Stick Fun, 1992	Georgiana Stewart	Kimbo Educational, Long Branch, NJ

APPENDIX E: MQRTB Rating Task

Figures E.1 and E.2 show the how the MQRTB rating scales appeared on the touchscreen. These two screens were used for each song until the MQRTB was completed.

An introductory screen stated the following information:

- Please rate the sound quality of each musical piece on the scales provided.
- There are no right or wrong answers. This is solely your opinion about how each song sound through your cochlear implant.



Please rate the sound quality of the song you are now hearing on the scales below.

Ratings:

PLEASANTNESS

unpleasant — pleasant

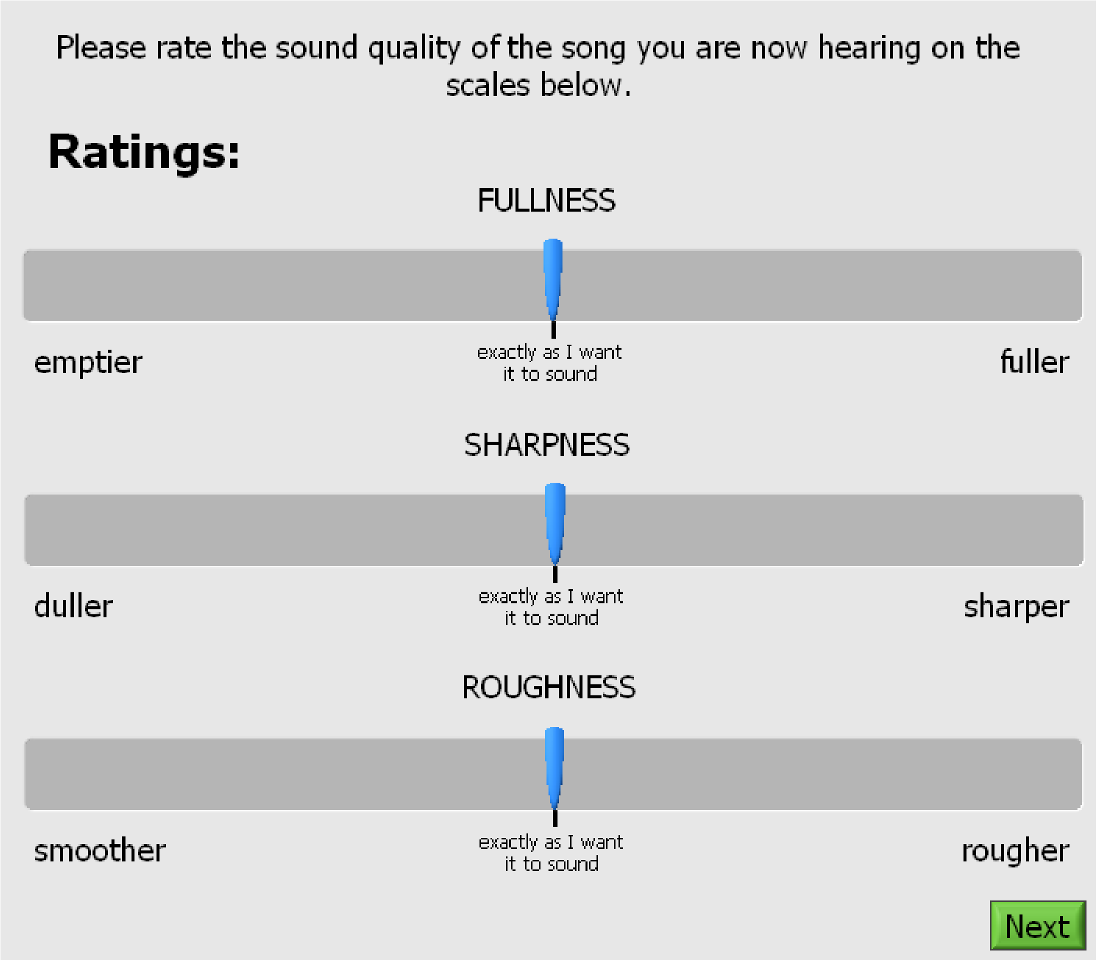
NATURALNESS

unnatural — natural

RICHNESS

tinny — rich

Figure E.1: Screenshot of the first screen of the MQRTB.


Please rate the sound quality of the song you are now hearing on the scales below.

Ratings:

FULLNESS

emptier — exactly as I want it to sound — fuller

SHARPNESS

duller — exactly as I want it to sound — sharper

ROUGHNESS

smoother — exactly as I want it to sound — rougher

Figure E.2: Screenshot of the second screen of the MQRTB.

APPENDIX F: Music Training and Background Questionnaire

SUBJECT INFORMATION

Name: .... Date: ....

Date of Birth: .... Age: ....

COCHLEAR IMPLANT INFORMATION

Type of Implant (if known) : Sonata$_{TI}^{100}$ / Pulsar$_{CI}^{100}$ (Circle one)

Ear Implanted: ☐ **Left** ☐ **Right**

Do you use a different program or setting for listening to music: ☐ **Yes** ☐ **No**

If yes, please specify (if known): ....

Date of 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

a) Prior to your hearing loss, how often did you choose to listen to music (eg. radio, tape, CD, concerts etc.)?

☐ Very Often ☐ Often ☐ Sometimes ☐ Occasionally ☐ Never

Approximately .... hours per week

b) Since you received your CI, how often do you choose to listen to music?

☐ Very Often ☐ Often ☐ Sometimes ☐ Occasionally ☐ Never

Approximately .... hours per week

c) 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, and I do not enjoy it anymore.

☐ 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 it to be, before my hearing loss.

☐ Music is more pleasant sounding than I recall before my hearing loss.

d) 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

1) a. Have you ever had instrumental (or practical) music lessons (ie. specifically for a music instrument or voice/singing)?

☐ **Yes** ☐ **No** *If yes, please detail:*

Instrument	Number of years of lessons	Age received lessons
____________________	______________________	___________________
____________________	______________________	___________________

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

☐ **Yes** ☐ **No** *If yes, please detail:*

Instrument	Grade level achieved
_________________________	_____________________
_________________________	_____________________

2) 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, please detail:*

	Place	*Number of Years*	*Age involved in class(es)*
☐	**Primary School**	________	______________
☐	**High School**	________	______________
☐	**University**	________	______________
☐	**Polytechnic/TAFE**	________	______________
☐	**Adult College**	________	______________
☐	**Other (*specify*)** ___________	________	______________

3) Have you ever been involved in a music group or ensemble (eg. band, choir, orchestra etc.)?

☐ **Yes** ☐ **No** *If yes, please detail:*

Group	Number of years	Age at which involved
______________________	__________	__________
______________________	__________	__________

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

☐ **Yes** ☐ **No** *If yes, please detail:*

Type of class	Number of years	Age at which involved
______________________	__________	__________
______________________	__________	__________

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

☐ **Yes** ☐ **No** *If yes, please detail:*

Type	Number of years	Age at which involved
______________________	__________	__________
______________________	__________	__________

6) Please detail any informal music classes, activities, experiences etc. that you have been involved in (eg. "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.

7) 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).

a) Knowledge of music history:	**1**	**2**	**3**	**4**	**5**
b) Knowledge of music theory:	**1**	**2**	**3**	**4**	**5**
c) Ability to read music:	**1**	**2**	**3**	**4**	**5**
d) Ability to play an instrument or sing:	**1**	**2**	**3**	**4**	**5**
e) Overall music ability:	**1**	**2**	**3**	**4**	**5**

***Comments*:**

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

8) Since you received your implant, have you:

a) Ever had formal instrumental (or vocal) music lessons: ☐ **Yes** ☐ **No**

If yes, please detail:

b) Ever attended music appreciation, music history or music theory lessons: ☐ **Yes** ☐ **No**

If yes, please detail:

c) Ever participated in a music group or ensemble (eg. choir, band, orchestra etc.):

☐ **Yes** ☐ **No**

If yes, please detail:

d) Ever taught yourself a music instrument, singing or music theory? ☐ **Yes** ☐ **No**

If yes, please detail:

____

e) Ever tried to improve your music perception ability? ☐ **Yes** ☐ **No**

If yes, please detail:

____

9) Do you have any other additional information or comments?

____

____

____

____

____

____

THANK YOU FOR YOUR TIME

APPENDIX G: Favourite Songs Provided by the Participants in the FSP versus HDCIS Study

Each participant was asked to supply two of their favourite songs, which were used to supplement the MQRTB. This individualised the MQRTB for each participant, and allowed for comparison of familiar to favourite songs to investigate whether the level of familiarity had an effect on music quality ratings. The favourite songs provided by each participant are shown in Table 42.

Table 42: The favourite songs supplied by each participant for the comparison of FSP and HDCIS CI study.

	Song	Artist	Year of Release
CI1	To Everything There is a Season	The Seekers	1962
	Balada para Adelina	Richard Clayderman	1976
CI2	Hotel California	The Eagles	1976
	Bohemian Rhapsody	Queen	1975
CI3	Heartaches by the Number	Guy Mitchell	1959
	When I Fall in Love	Nat King Cole	1957
CI4	Cootamundra Wattle	John Williamson	1986
	Green Fields of France	Eric Bogle	1976
CI5	My Way	Paul Anka	1969
	Save the Last Dance for Me	Paul Anka	1963