Chapter 6

DISCUSSION OF RESULTS

Chapter aim: The aim of this chapter is to explain the meaning and value of the results obtained in the previous chapter and to compare it with existing literature.

6.1 INTRODUCTION

The methodological approach specified in Chapter 4 provides the operational framework for the collection of data and the realization of the aims of this study. Although data collection is an important step in the research process, the method used for interpreting the data is the key to research success (Leedy & Ormrod, 2001:88). The interpretation of data is necessary, since this is the step that provides meaning to the total research process (Leedy & Ormrod, 2001:88).

Because there is no evidence in the literature of previous studies that evaluated music perception with frequency lowering hearing aids (Scollie *et al.*, 2008:8), there was no definite indication of what to expect in terms of the results of the current study. Studies conducted with various speech stimuli and frequency lowering hearing aids show a definite improvement in different aspects of speech perception (Bagatto *et al.*, 2008: par. 16; Glista & McDermott, 2008:1; Nyffeler, 2008b:22; Scollie *et al.*, 2008:2). In speech however, the frequencies at or above 1 kHz contribute the highest percentage of the importance of a speech signal for intelligibility (Revit, 2009:12). For music, almost the opposite is true. Although the highest orchestral pitches may reach 4 kHz - 5 kHz, the overwhelming majority of the musical pitches exist in the lower half of the auditory spectrum – at approximately 1 kHz and below (Revit, 2009:14). If one takes into account that the frequency lowering hearing aids compress the high frequencies that cannot be aided into the low frequency region where more hearing is preserved (Glista & McDermott, 2008:1), one may easily assume that frequency lowering hearing aids will be more beneficial with speech stimuli than with music input. This, however, would be the wrong assumption and can easily be proved incorrect when one considers the complexity of music (Don *et al.*, 1999:155) as described earlier.

In the light of the aforementioned, the data collected for this study was analysed and interpreted by systematically discussing it for each sub-aim as presented in Figure 5-1 of the previous chapter. Discussions according to the sub-aims are intended to provide insight into the different aspects of music perception. By providing answers to the sub-aims, the main aim of the study, i.e. to determine the influence of non-linear frequency compression on the perception of music by adults presenting with a moderate to severe hearing loss, was realised.

6.2 DISCUSSION OF THE RESULTS ACCORDING TO THE SUB-AIMS

Throughout the discussion of the results, the researcher will sometimes refer to literature regarding cochlear implants and music perception since very few studies regarding the perception of music with hearing aids exist (Looi *et al.*, 2008b:421). It should be taken into account, however, that results from the various studies differ due to different target beneficiaries, methodological differences, bigger differences in implementation and different frequency lowering strategies involved. All these differences may result in a difference in the sound quality that participants perceive and therefore have the potential to influence the music perception benefit.

Compilation of a music perception test to use as data-acquisition material

Results obtained from audiological and musical professionals regarding the format, content and conduction procedures of the MPT confirmed that this test is suitable for the assessment of music perception in hearing aid users. This was also confirmed by results obtained from hearing aid users, since all of them were able to perform the tasks on the test. As there currently is no standard test of music perception (Wessel *et al.*, 2007:1), it is believed that the MPT will be a valuable addition to the audiological test batteries for music perception.

The influence of non-linear frequency compression on the perception of rhythm

The high scores obtained for the different rhythm sub-tests by hearing aid users in the present study (with and without NFC) are not unexpected; previous studies (Looi *et al.*, 2008b; Flynn *et al.*, 2004) showed that adults with a hearing loss increase their reliance on temporal cues as their hearing loss increases. This reliance on temporal cues is logical given that, for most severe hearing losses, frequency resolution is lost while temporal information remains largely intact (Flynn *et al.*, 2004:480). Furthermore, as Looi *et al.*, (2008a:265) confirmed, adults with a hearing loss generally perceive rhythm as competently as adults with normal hearing and one may assume that the perception of rhythm is not really problematic for hearing aid users and therefore the activation of NFC, as a different hearing aid processing strategy, would not result in major increases in their performance. Lastly, temporal patterns in music that impact a distinctive rhythm generally occur in the approximate frequency range of 0.2 to 20 Hz (McDermott, 2004:57) and therefore NFC does not have an influence on these low frequency stimuli. This was confirmed by the <u>rhythm identification</u>, <u>rhythm recognition</u> and <u>rhythm perception</u> tasks which showed no significant improvement in participants' performance with NFC. Although slightly higher scores were obtained with NFC, these differences were individual and hearing aid users should decide for themselves whether they are able to determine a difference in the perception of rhythm with and without using the NFC strategy.

The only rhythm task in which hearing aid users seemed to demonstrate superior performance with NFC, was the <u>rhythm discrimination</u> task. This may be explained by the fact that stimuli included in this sub-test ranged around 3959.8 Hz and the NFC cut-off frequency ranged between 2.4 kHz and 4 kHz for most participants. Results obtained by this sub-test are similar to the findings of previous rhythm perception assessments done in cochlear implantees and hearing aid users (Cooper *et al.*, 2008; Looi *et al.*, 2008b; Leal *et al.*, 2003; Gfeller & Lansing, 1992), in the sense that both normal hearing participants and hearing aid users obtained significantly high scores for this task. The results, however, differ from the studies mentioned above in the sense that hearing aid users in the current study obtained lower average scores than the hearing aid users and cochlear implantees in previous studies where all scored above 80%. One reason for this may be that the stimuli used in these studies were composed of lower frequencies than those in the MPT and therefore one can assume that participants will perform poorer with high frequency stimuli compared to low frequency stimuli where more residual hearing is available. Furthermore, stimuli used in the other studies consisted of short rhythm excerpts whereas the stimuli used in the MPT consisted of longer rhythm excerpts, making the task more complex. Another possibility is that, in the present study, the hearing aid users were on average 27 years older than the normal hearing listeners. The performance difference may be due, at least in part, to the age difference between the groups. Kong *et al.*, (2004:181) found that older listeners (age range 65-76 years) performed significantly poorer than younger listeners (age range 18-40 years) on temporally mediated measures, particularly in more complex stimulus conditions. Although no participants above the age of 65 years were included in this study, there still is a significant age difference between the average ages of 30.4 years for the normal hearing participants and 57.7 years for the hearing aid users and therefore this aspect warrants further investigation.

With the above taken into account, it is clear that NFC does not significantly influence the perception of rhythm positively or negatively. A last aspect to take into consideration is that of music training. A task similar to the rhythm identification and rhythm perception tasks was done by Rammsayer and Altenmuller (2006:40) in which they assessed temporal skills in musicians compared to non-musicians. They concluded that superior temporal acuity for musicians compared to non-musicians was shown for rhythm tasks such as the ones described above. Results of the current study could however not confirm these findings as there was no indication that participants who received musical training obtained higher scores on the rhythm identification and perception tasks.

The influence of non-linear frequency compression on the perception of timbre

The lower scores obtained by hearing aid users compared to normal hearing listeners can be explained by the fact that accurate timbre perception requires the perception of both the signal's temporal envelope and the energy spectrum of its harmonic components (Looi *et al.*. 2008b:431). Modifying features of the temporal envelope or changing the frequencies and/or amplitude of the harmonic components could alter the perceived timbre (Looi *et al.*, 2008b:431). The comparatively poorer identification results for participants with a hearing loss compared to normal hearing participants may suggest that the hearing aid does not sufficiently transmit the broad spectral envelope and/or temporal envelope information from the input signal to enable accurate perception of timbre (Looi *et al.*, 2008b:431). This may have arisen from a range of factors. For a normal hearing individual, such spectral selectivity derives from the different frequency components of the acoustic stimulus being separated into different auditory filters, with each frequency component resulting in activity at discrete sites along the basilar membrane. For hearing aid users, perceptual smearing may occur as a consequence of auditory filter anomalies associated with cochlear hearing loss, poor neural survival patterns and poor frequency selectivity. This may cause diminished spectral clarity of the stimuli for the subject (Looi *et al.*, 2008b:431).

The slight improvement in participants' score with NFC for the instrument identification tasks can be attributed to the activation of NFC which enables hearing aid users to hear more high frequency information than previously (McDermott & Knight, 2001:121). Although the majority of music pitches have fundamental frequencies at approximately 1 kHz and below (Revit 2009:14), the perception of high frequency information is important for timbre related tasks because resonances occurring above the fundamental frequency of music notes help the listener to distinguish the sound of one instrument from another (Revit, 2009:14). The resonances of music instruments are usually determined by fixed geometric properties of the instrument, creating emphasis at one or more of the upper harmonics of a given note and although instrumental harmonic resonances may occur in that same range, they often extend much higher in frequency, for example the violin, which often has significant harmonics above 5 kHz (Revit, 2009:14). If a participant can only hear the fundamental frequency of the musical notes, he/she will be able to hear the balance of one note against another, but will still have difficulty distinguishing between the sounds of different instruments. Furthermore, it is well-known that tones falling in a dead region may have an abnormal timbre (McDermott & Dean, 2000:353). As it is assumed that all participants had high frequency dead regions, it implies that without NFC they would perceive the timbre of the various musical instruments abnormally and therefore have increased difficulty (depending on the extent of the dead region) to correctly identify one instrument from another, resulting in decreased scores on the instrument identification tasks.

Regarding the results of Sub-test 5, one should remember that participants were only assessed on instruments they were familiar with. In the case of participants who, for example, scored 100%, the score does not necessarily imply that they were able to identify all the answers in the test correctly, but rather that they were able to correctly identify all the items containing musical instruments with which they were familiar. If one looks at participant 17's performance on the multiple instrument identification task, he/she obtained 100% with both NFC settings. However, only the piano, flute and violin were considered in his/her assessment because these were the only instruments which the participant was familiar with. Of all the instrument combinations included in this sub-test, only one combination (piccolo flute/piano) was applicable for assessment as all the others included at least one instrument with which the participant was not familiar. This can explain the perfect score obtained by participant 17 in both cases, because the piano and the piccolo flute were a combination of two instruments instead of three, therefore making it less complex; these were also two of the instruments that were most frequently identified correctly, as described in the previous section.

Analysis of results confirmed that participants correctly identified the piano, violin, piccolo flute and trumpet most often and the trombone and clarinet least often. This correlates with the familiarity ratings of the music instruments as presented in Figure 5-10 in the previous Chapter. Confusion metrics showed that the clarinet (D4/293.7 Hz - C5/523.3 Hz), which produced a mid frequency sound, was most often confused with the piccolo flute (D7/2349 Hz - C8/4186 Hz) which produced a high frequency sound. The cello (D2/73.42 Hz - C3/130.8 Hz) was most often confused with the trombone (D1/36.71 Hz - C2/65.41 Hz) and vice versa – both these instruments produced low frequency sounds. Participants performed significantly better in identifying single than multiple instruments playing together; the same was reported by Looi *et al.*, (2008b:428) who compared this ability of cochlear implantees to that of hearing aid users.

For the number of instruments task, participants obtained a statistically significant benefit with NFC. This can again be explained by the fact that participants were able to hear more of the high frequency musical resonances with the activation of NFC as this algorithm provided them with additional high frequency information (McDermott *et al.*, 1999:1323). Another aspect to take into account is that when one listens to music, one groups tones that are similar in timbre together and separate those of substantially different timbre (Deutsch, 2007:4475). Therefore, when different types of instruments play in parallel one often forms groupings based on timbre, even when the tones produced by the different instruments overlap considerably in pitch (Deutsch, 2007:4475). Again, high variability in participants' scores was found, irrespective of using NFC or not.

With regard to the number of instruments task it was seen that although hearing aid users obtained lower scores than with the single instrument identification task, their scores were much higher than the average scores obtained for the multiple instrument identification task. This can be explained by the fact that Sub-test 6 was not as complex as Sub-test 5, in that it only required participants to identify how many different instruments they could hear playing in an ensemble instead of identifying each instrument. Furthermore, the instruments included in Sub-test 6 were each selected to have a timbre as different as possible from the others, whereas the instruments included in Sub-test 5 were much more similar in timbre. Generally, it was noted that instruments such as the snare drum and xylophone were more likely to be discriminated as the distinctive temporal envelopes of these instruments may have provided salient durational or rhythmical cues. High error rates were again seen on items with more instrument combinations compared to items with fewer combinations of instruments.

To conclude, it seems that NFC significantly benefits the perception of timbre. Again, it seems that music training may affect participants' performance on timbre related tasks; Cooper *et al.*, (2008:624) found that training improved instrument identification by cochlear implantees. This, however, does not seem to be the case for hearing aid users in the present study, since those who had formal music training obtained average scores for the timbre section. Again, the only conclusion one can reach centres on the high variability in participants' scores; one has to add, however, that the relationship between hearing aid users' ability to perceive timbre and their level of music training warrant further investigation.

The influence of non-linear frequency compression on the perception of pitch

Perceiving the pitch of a complex sound primarily requires listeners to extract information about fundamental frequency from the complex acoustic signal (Looi *et al.*, 2008b:429) and listeners are believed to make musical interval judgments on the basis of differences in pitch value or on the basis of ratio relationships between the fundamental frequencies of the notes comprising the interval (Pijl, 1997:370). As Revit (2009:14) indicated, the greater part of pitch in music exist in the lower half of the auditory spectrum, with corresponding fundamental frequencies at approximately 1 kHz and below. With the human singing voice, almost all of the perceived pitches originate from fundamental frequencies below 1 kHz.

It is well-known that cochlear damage leads to changes in perceived pitch or to reduced accuracy in pitch perception (Ricketts *et al.*, 2008:169; Moore, 1996:143) and that pure tones are often described as sounding highly distorted or noise-like when falling in a dead region (Moore, 2001a:24). Furthermore, results of previous studies (Moore, 1996:144) indicated that people with cochlear damage depend relatively more on temporal information and less on spectral information than normal hearing listeners when perceiving pitch. International research also confirms that pitch and frequency discrimination of both pure and complex tones are worse than normal in persons with sensory neural hearing loss ((Moore *et al.*, 1992:2892). It is therefore not surprising that hearing aid users in general scored less than normal hearing listeners on the pitch tasks.

However, in persons with a sloping hearing loss the low frequency hearing greatly assists with pitch perception and would be expected to enhance their enjoyment and appreciation of music in general (McDermott, 2004:79). Participants included in this study mostly had more severe hearing losses at the high frequency region with hearing in the low frequency region being more intact. If it is taken into account that low frequency hearing greatly assists with pitch perception since hearing aid users mainly rely on the fundamental frequency information when perceiving pitch (which is mostly below 1 kHz) and that the NFC algorithm did not influence low frequency hearing, it is not surprising that participants did not benefit from NFC for the pitch identification and pitch discrimination tasks. Therefore, one can conclude that NFC does not have a clear positive or negative influence on the perception of pitch.

There seems to be some discrepancy in the literature regarding whether music knowledge or training may improve pitch perception. Van Egmond and Boswijk (2007:31), for instance, found that music training improved the processing of tonal music but also concluded that non-musicians without music training are also capable of identifying tonics in music excerpts perfectly. Looi *et al.*, (2008b:428), however, found no significant correlation between performance on pitch tasks and the music experience of participants, but also indicated that participants showed improved scores on pitch perception tasks after a training period was allowed. It should be noted, however, that this training period was task specific and therefore cannot be generalized to pitch perception and music training in general. In the present study no definite correlation between music training and pitch perception could be established. All the participants who had music training scored on average 60% or higher for the pitch section of the MPT, which is marginally less than the average score of roughly 67%. It is interesting that the participant who obtained the highest score on the pitch section (between 90% and 100% depending on the NFC setting) had several years of music training. Therefore it seems that music training may influence hearing aid users' performance on pitch perception tasks, but further research is needed for confirmation.

<u>*The influence of non-linear frequency compression on the perception of melody*</u>

A question arises as to what it really is that enables people to recognize melodies. Sequences of music notes do not have specific semantic referents as sequenced words do (e.g. phrases, sentences, etc.) but through cultural practice particular pitch patterns become cohesive melodic units, which are identified by song titles (e.g. 'Happy birthday'). Gfeller *et al.*, (2002:30) indicated that persons with normal hearing and no training in music easily recognize familiar melodies. Structural features that contribute to this ability include the overall contour[21] of the melody, the exact pitch changes form one note to the next (e.g. C4 to E4) and the rhythmic pattern in the melody. Melodic contour is especially important when listeners are first learning new melodies, whereas exact pitch intervals are of greater importance in the recognition of familiar melodies (Gfeller *et al.*, 2002:30).

One of the primary consequences of music's relational system is the creation of expectation in the listener based on a prior internalization of certain relational variables (Limb, 2006:438). Most music listeners are accustomed to hear music notes that fit properly within the contextual musical reference, whether melodic, rhythmic, or harmonic. A corollary of the notion of musical expectancies is that of violations of musical expectancies, which are tantamount to violations of musical syntax. For example, if a simple melody is played entirely within one key (e.g. G major), but the last note of the melody is out of key (e.g. G# instead of G natural), the listener detects a syntactic aberration within the presented melody (Limb, 2006:438). To be able to do this, participants listen to the differences in pitch (Limb, 2006:442; McDermott, 2004:60). If one takes into account that there is no real benefit for pitch tasks with NFC and that participants rely on differences in pitch to perform the <u>musicality perception</u> task, it is not surprising that participants obtained basically the same score for this task with both NFC settings. Furthermore, this task of discriminating between different pitch contours is related to melody identification, but is generally more difficult because of the reduced number of auditory cues available in the test material (McDermott, 2004:60). With this taken into account, it is to be expected that hearing aid users would obtain lower scores for this task, i.e. (49%) compared to the pitch identification (71% - 73%) and pitch discrimination (62 - 63%) tasks where participants also relied on pitch information for completion of the tasks.

[21] Refers to the overall pitch movement higher or lower (Gfeller *et al.*, 2002:30)

It is well-known that a hearing loss has a significant impact on melodic perception (Gfeller & Lansing, 1992:21) and therefore it is not unexpected for persons with normal hearing to perform superiorly on melodic perception tasks to hearing aid users. It does however seem that, with NFC, participants perform slightly better when asked to identify familiar melodies than without NFC, although this benefit was not statistically significant. This is slightly more difficult to explain if one considers that recognition of melodies depend on the exact pitch intervals and rhythmic information of the melodies and that participants did not experience a real advantage with NFC for the perception of pitch (section 6.2.4) and rhythm (6.2.2). One possible explanation for the positive outcome with NFC might be that the melodies were played in a range of 880Hz to 4186Hz and therefore contained relatively high frequency information. As the NFC cut-off frequency for most participants ranged between 2.5 kHz and 4 kHz one can assume that more frequency compression took place than with the stimuli included in the pitch and rhythm sections of the MPT.

Error pattern analysis showed that hearing aid users performed less accurately in the identification of melodies without rhythm cues (56.4%) compared to melodies with rhythm cues (79.5%) and that melodies with similar rhythmic patterns were confused more often than melodies with very different rhythmic structures for example, participants often got confused with 'Mary had a little lamb' and 'Twinkle, twinkle little star'. It is not surprising that hearing aid users experienced more difficulty identifying melodies without additional cues; this is a more complex task due to the fact that they have to rely only on one source of information (pitch) instead of two.

It is not possible to compare the results of the current study with those of similar previous studies because there is a high degree of variability in the results obtained by the different studies due to different methodological approaches implemented. Most of the international studies assessed the melody recognition skills of cochlear implantees (Singh *et al.*, 2009:161; Galvin *et al.*, 2007:308; Gfeller *et al.*, 2005:245; Kong *et al.* 2005:1356; Kong *et al.* 2004:179; Leal *et al.*, 2003:830; Gfeller *et al.*, 2002:40; Fujita & Ito, 1999:635). The only study involving hearing aid users was done by Looi *et al.*, (2008b:428). They compared the melody identification skills of hearing aid users to that of cochlear implantees. They found that hearing aid users scored on average 91% for the task compared to 52% by cochlear implantees (Looi e*t al.*, 2008b:428). For the stimuli presented in their study the rhythmical structure of the melodies was intact, whereas the stimuli included in the current test included melodies with and without rhythm cues. This may be one possible explanation for the high score differences obtained by hearing aid users in the current study and the study by Looi *et al.*, (2008b) as it is easier to recognize melodies which are presented with both pitch and rhythm cues instead of focusing on pitch cues only.

Since cochlear hearing loss often involves damage to the outer hair cells (Moore, 1996:133) and consequences of outer hair cell loss include difficulty in understanding speech, especially in the presence of background noise (Kluk & Moore, 2006: par. 5), one may assume that hearing aid users would have difficulty with the identification of musical stimuli presented in the presence of background noise. This was confirmed by the low scores obtained by participants for the music-in-noise song identification task. It is difficult to explain the slight benefit obtained with NFC in this task as there seems to be a discrepancy in the literature regarding the influence of NFC on stimuli presented against background noise. Moore (2001a:30) highlighted one of the potential problems of frequency lowering hearing aids, i.e. when background noise is present portions of the noise, which were previously inaudible, may be lowered to a frequency region where it is more audible and this might offset any advantage that would otherwise be gained from the lowering. Gifford *et al.*, (2007:1200) however found that participants benefited from digital frequency compression when speech was presented against background noise. As a slight benefit with NFC was also seen for the melody identification task one may assume that NFC could benefit the identification of soundtracks in the presence of noise. The identification of music in noise is however more complex and therefore participants' scores were substantially lower than for the identification of melodies without noise. These results could not be compared to those of other studies since no similar music-in-noise task could be found in the literature. The only other study that involved music stimuli and noise was done by Spitzer *et al.*, (2008:60) where discrimination of music versus noise for cochlear implantees were assessed and they found that cochlear implantees could successfully discriminate between these two stimuli.

When the results for the different melody sub-tests are viewed holistically, it is evident that NFC significantly improves the perception of melodic stimuli. Again there seems to be a discrepancy in the literature as to whether music training influences melody perception. Limb (2006:438) indicated that the ability to detect music aberrations is likely to be dependent on the degree of music training and Leal *et al.*, (2003:834) confirmed that cochlear implantees with training in music were more capable of recognizing familiar melodies. Kong *et al.*, (2004:182) could, however, not find a relationship between melody identification and music training in cochlear implantees, while Gfeller *et al.*, (2002) indicated that formal music training is not a particularly strong predictor of perceptual accuracy for melody recognition by listeners with cochlear implants. Results from the present study could not identify a definite relationship between performance on melody tasks and music training as the scores of participants who received training in music differed substantially.

<u>The influence of non-linear frequency compression on participants' subjective impression of listening to music</u>

Music perception and enjoyment are influenced by a number of important factors beyond personal taste when the music is perceived through an assistive device like a hearing aid (Gfeller *et al.*, 1997: par. 1). Several variables that have a probable impact on musical perception and enjoyment include the structural characteristics of the music itself (melodic, rhythmic and harmonic structures), differences among listeners irrespective of the hearing aid (e.g. the listening habits of the person before the hearing loss and after receiving hearing aids), as well as the technical features of the particular device (Gfeller *et al.*, 1997: par. 2). As a category of environmental sound, music includes a considerable variety of structural elements presented in manifold combinations and styles that occur within a cultural context. Everyday listening experiences typically include a variety of instrumental and vocal tone qualities (timbre), harmony accompanying the melodic line and these elicit different analytical and affective responses in the listener (Gfeller *et al.*, 1997: par. 45).

Participants in the present study were asked to provide a subjective impression of how they experienced listening to music with and without NFC in terms of the following qualities of music:

- *Loudness*

It was not surprising that most of the participants were satisfied with the loudness of music since the hearing aids used in this study were power hearing aids with an 80 dB of peak gain and 141 dB maximum power output (Bohnert *et al.*, 2010:2). Two of the complaints most commonly voiced by hearing aid users are that music is overall either too loud or too soft (Leek *et al.*, 2008:523). When one considers that music is louder than speech (Chasin &

Schmidt, 2009:32) and that all participants used a standard program for listening to both music and speech, one would think that some participants could experience the music as being too loud. The only possible explanation for their satisfaction with the loudness of music may be that all hearing aids were fitted on target as verified with real-ear measurements and in so doing the researcher probably ensured that sounds were not uncomfortably loud. If one considers that the loudness of the sound produced by the hearing aid is determined by the gain and maximum power output of the hearing aid, it is not surprising that NFC did not have a big influence on loudness.

Previous research (Leek *et al.*, 2008:521) indicated that participants had to continually change the volume setting on their hearing aids while listening to music while only 34% of the participants in a more recent study indicated volume changes as a problem. Most of the participants in the present study were satisfied with the volume settings of their hearing aids (irrespective of using NFC or not) when listening to music; it therefore seems that changes in loudness within a piece of music cause less difficulty than before. These improvements can be contributed to the improvements in hearing aids over the years, particularly in the use of wide-dynamic-range-compression technology (Leek *et al.*, 2008:523).

- *Fullness*

Normal hearing listeners tend to judge sounds richer in harmonics as more full whereas cochlear implantees have often described the quality of musical instruments as sounding more thin or shrill compared to how instruments sounded prior to deafness (Gfeller *et al.*, 2002:138). No research on how hearing aid users described music in terms of fullness could be found in the literature. Overall, hearing aid users in the present study seemed to be relatively satisfied with the fullness of the music and there was a slight preference towards listening with NFC, although not statistically significant. The contribution of NFC towards the fullness of music can be explained by the fact that it enables participants to hear the high frequency sounds of music which they previously missed. Although the majority of music pitches exist in the lower half of the auditory spectrum, the higher frequencies are also important for music (Revit, 2009:14). Resonances occurring above the fundamental frequency of music notes help the listener to distinguish the sound of one instrument from another and add to the harmonic quality of the sound. Instrumental harmonic resonance may occur at much higher frequencies than 3 kHz; for example, the highest notes of a harmonica can even have significant harmonics as high as 10 kHz (Revit, 2009:14). Music is very dynamic and the variety in instrumental timbre (e.g. the more characteristically hollow sound of the clarinet versus the very rich and deep sound of a cello) contributes to the novelty and beauty that listeners seek in music and therefore one sound being judged to be more empty than another is not inherently undesirable (Gfeller *et al.*, 2002:138).

- *Crispness*

Hearing aid users often complain of music being blurred and distorted and that melodies are therefore difficult to recognize (Leek *et al.*, 2008:520). Normal hearing listeners have judged sounds having more low-frequency energy as more dull or blurred in quality, whereas sounds having more high frequency energy were judged as more sharp (brilliant) or crisp (clear) in quality (Gfeller *et al.*, 2002:138). With this in mind, it is not surprising that participants rated music as being more crisp and clear with NFC because they were then receiving high frequency information otherwise missed. This preference was however not statistically significant. The balance between the amounts of high and low frequency amplification should however be optimal since hearing aid users do not consistently prefer extended high frequency stimuli for listening to music (Wessel *et al.*, 2007:3).

- *Naturalness*

It is not clear whether people with hearing loss who wear hearing aids can separate the effects of the loss from the alterations in music produced by the hearing aids (Leek *et al.*, 2008:525) and therefore their definition of naturalness can easily be compared to what they are used to (not hearing all the sounds in music and when presented with more sounds than they are used to, it does not seem natural anymore). This is especially possible for persons with a longer onset of hearing loss and persons who have been wearing hearing aids for a longer period of time. No findings regarding the perception of naturalness of music by persons with a hearing loss could be found for comparing with the results of the current study. It is assumed that the naturalness of the sounds of music will influence participants' perception of the pleasantness of music stimuli and therefore this aspect should be viewed in conjunction with participants' assessments of the pleasantness of music, which are discussed later.

- *Overall fidelity*

Normal hearing listeners have rated sounds with more noise as sounding more scattered or narrow (Gfeller *et al.*, 2002:138), while hearing aid users often complained that some music instruments sounded odd, as if they could not hear the whole spectrum of an instrument's sound (Chasin, 2003b:40). Results of the present study indicate a definite preference and statistical significant benefit for music being more dynamic with NFC. Again, this may be contributed to the high frequency music sounds that participants missed without NFC and therefore they were not able to hear the whole spectrum of certain music instruments. Being able to hear the whole spectrum of different instrument's sound adds to the aesthetic experience of music (Hockley *et al.*, 2010:33; Gfeller *et al.*, 2002:349) and therefore one can conclude that the activation of NFC add to the unique and rich timbre of music.

- *Tinniness*

Participants reflected a statistically significant improvement in the perception of musical tinniness with the activation of NFC. The perception that music sounds less tinny with the use of NFC is actually surprising if one considers that NFC provides listeners with more high frequency audibility and previous research indicated that persons with a hearing loss did not necessarily like a high frequency emphasis when listening to music (Leek *et al.*, 2008:520; Wessel *et al.*, 2007:3). It was further found that with frequency compression hearing aids sounds might have a tinny sound when lowered too much (Scollie *et al.*, 2008:7). One possible explanation for the indication that music sounds less tinny with the activation of NFC may be that the NFC setting for each participant was left on the default setting determined by the hearing aid fitting software and was only adjusted (making the NFC setting weaker, in other words less frequency compression takes place) when participants complained about sounds being too tinny or uncomfortable. In so doing the researcher ensured that none of the participants received too much high frequency amplification and therefore avoided sounds having a tinny quality.

- *Reverberance*

Perceptions regarding this musical quality are similar to the way participants experience the tinniness of music, because too much high frequency amplification often causes sounds to have an echo. Again it is surprising that less participants complained about hearing echoes with NFC since they were actually exposed to more high frequency information, but nevertheless this improvement was also statistically significant. The fact that the researcher ensured that the NFC setting was comfortable for each participant without causing any disturbances in sound quality might serve as a possible explanation for this phenomenon.

- *Pleasantness*

When asked to rate the pleasantness of music, participants indicated that they experienced music slightly more pleasant when listened to with NFC; however, this benefit was not statistically significant. As music is very complex and there is no single characteristic that determines the pleasantness of music (Leal *et al.*, 2003:826), one can assume that all the qualities of music described above contribute to the way listeners experience music. From the discussion above it is evident that participants rated the fullness, crispness, naturalness, overall fidelity, tinniness and reverberance of music stimuli to be more pleasant with NFC active compared to inactive and therefore it is not surprising that they rated music to sound slightly more pleasant with NFC active. Other aspects that might influence the enjoyment of music is participants' ability to detect different music instruments, discriminate rhythm, distinguish between high and low notes and hear the melody as well as the lyrics in a given piece of music piece. For all these aspects participants indicated superior quality with the use of NFC. It is extremely important to take these aspects into consideration in order to provide hearing aid users with a pleasant music listening experience because most people choose to listen to music for personal pleasure and enjoyment (Gfeller *et al.*, 2002:349),.

When asked whether they felt that their enjoyment of music has decreased since experiencing hearing problems, 60% of the participants in the current study answered affirmatively. Factors that were previously identified as correlating with a person's enjoyment of music after having been diagnosed with a hearing loss include (Leek *et al.*, 2008:520-523):

- Music training: Persons with training in music were more likely to report a loss in enjoyment of music since developing a hearing loss compared to persons without such training. In the present study, however, no correlation could be established in this regard.

- Degree and slope of hearing loss: Persons who noted a change in the enjoyment of music had milder hearing losses or hearing losses with a flatter audiometric configuration. All participants in the current study had a moderate to severe hearing loss. It was however noted that participants who had a ski-slope hearing loss with better thresholds in the lower frequencies complained less about a decrease in musical enjoyment, possibly because the relatively good low frequency hearing assisted in the perception of music stimuli.
- Period with hearing loss/hearing aids: People who reported a change in music enjoyment had a hearing loss for a shorter time relative to those experiencing no change in music enjoyment and had worn hearing aids for a shorter period of time. These characteristics suggest that changes in music enjoyment might be more apparent in people who have recently developed a hearing loss significant enough to wear hearing aids. It is possible that the music memories of these people are somewhat fresher than is the case in people with more long-standing hearing losses. A similar phenomenon was noted in the current study where participants who used hearing aids for three years or less felt more strongly about a decrease in music enjoyment than participants who had hearing aids for longer than three years.
- Individual age: Persons who reported no change in music enjoyment with the onset of their hearing loss were usually older. This could not be verified by the results from the current study since participants that felt stronger about a decrease in musical enjoyment with the onset of their hearing loss ranged over various ages and were not restricted to younger participants only.

When asked whether they removed their hearing aids while listening to music, 80% of the participants in the current study answered negatively. A similar observation was recently made by Leek et al., (2008:523) who reported that 78% of the participants in their study chose to wear their hearing aids while listening to music. Given that fewer participants removed their hearing aids when listening to music, it might appear that some aversive aspects of music processed by hearing aids have been reduced. Given that still a relatively large percentage of persons with hearing aids expressed a loss in enjoyment of music, audiologists should routinely ask patients about their music listening habits and should intervene in order to provide them with the best possible amplification options for listening to both speech and music.

The effect of extended use of non-linear frequency compression and acclimatization on music perception

It is widely acknowledged that hearing aid users may gain increasing benefit over longer periods of time. Munro (2010:11) and McDermott *et al.*, (1999:1334) concluded that it is possible that the performance of participants on speech perception tests with frequency lowering hearing aids would have improved for at least some of the participants in their study, had they been able to use the hearing aids for a longer period. In a recent study with NFC it was found that children showed continued speech perception improvement over time, with scores at a second evaluation exceeding those measured about a year earlier (Glista *et al.*, 2009: par. 24). In another study with linear frequency transposition it was found that a period of three to six weeks was required to realize the benefits of this algorithm for consonant identification and articulation (Auriemmo *et al.*, 2009:301), while Kuk *et al.*, (2009:478) recommended a trial period of one to two months with frequency lowering hearing aids before improvements in speech understanding may be realised.

With the above taken into account, a period of four weeks was allocated for acclimatization to NFC in the current study. After four weeks the initial assessments with NFC active and inactive were conducted as described above. It is however believed that real-life use and experience of frequency lowering hearing aids is necessary to reveal it's true potential (Kuk *et al.*, 2009:477) and therefore the researcher decided to do a second evaluation with NFC. The second evaluation was done three months after the initial evaluations took place in order to assess whether participants' objective as well as subjective perceptions of music increased with extended use of NFC.

- *Objective assessment*

In order to obtain objective results to determine whether extended use of NFC improved participants' perception of music, they were asked to complete the MPT again. Analysis confirmed that although participants' scores improved slightly for the perception of rhythm, timbre, pitch and melody in the second evaluation, these improvements were not statistically significant. Since it is well-known that repetition and learning may improve a person's performance on certain tasks or tests, it should be noted that participants never received any feedback during their previous evaluation with the MPT. There were no discussions regarding correct answers or error patterns and therefore one may assume that the improved performance on the MPT after three months could not be contributed to repeated exposure to the test material or to learning.

It therefore seems that although participants obtained a slight benefit in the perception of rhythm, timbre, pitch and melody after an extended period of use, a period longer than three months should be allowed to observe possible significant improvements. This is well warranted, since prior studies indicated that music instrument recognition of cochlear implantees may improve on the grounds of everyday listening experiences and training (Driscoll *et al.*, 2009:72) and that cochlear implantees showed a significant improvement in their ability to recognize familiar melodies when evaluated again after one year (Gfeller *et al.*, 2010:32). The literature referred to above involved cochlear implantees as participants; future research could be conducted with hearing aid users that are fitted with frequency lowering hearing aids in order to make definite conclusions.

- *Subjective assessment*

To determine whether participants' subjective impression of music improved after using NFC for a period of three months, they were asked to rate their everyday musical experiences again, according to the scale included in Questionnaire 2. Although participants perceived music as being slightly more natural with NFC during their initial assessment, this benefit was not significant. Participants did, however, perceive significant improvements in the musical qualities of loudness, fullness, crispness, overall fidelity, pleasantness and reverberance after using NFC for three months. The only quality which participants rated to decrease after extended use of NFC was that of the tinniness of music, which can possibly be contributed to the degree of the NFC setting. For the initial assessments the NFC setting was left on the default value as determined by the hearing aid fitting software. Most participants seemed to be satisfied with the tinniness of music at that time, with only one participant complaining about the music being too tinny or having an echo. Participants who used the NFC hearing aids for three months visited the audiology practice for fine tuning of the hearing aids after they acquired them. During these sessions, all of the participants, except one, had the NFC setting adjusted to be stronger, which implies that more high frequency information was lowered. Scollie *et al.*, (2008:7) found that when too much high frequency information was lowered sounds could have a tinny quality. It therefore seems that the additional lowering of frequencies might have been too much since participants preferred the default NFC setting.

The influence of non-linear frequency compression on the perception of music by adults presenting with a moderate to severe hearing loss

From the information described above, it is clear that NFC definitely has a positive influence on the perception of music and that this algorithm does not influence musical enjoyment negatively. There are, however, some additional aspects that one should take into account when reviewing the results, including participants' degree and slope of hearing loss, their gender, the NFC cut-off frequency on the hearing aids as well as the data logging values for hearing aid use by participants.

- *Degree and pattern of hearing loss*

For participants with a milder average hearing loss in the mid-frequency (1 kHz and 2 kHz) region, scores on some of the tasks (rhythm recognition, pitch identification and discrimination as well as melody identification) included in the MPT were significantly higher with both NFC settings than for those participants whose hearing losses at these frequencies were more severe. This phenomenon was also observed in the performance of participants with a more severe hearing loss in the high frequency (4 kHz and 8 kHz) region on the melody identification task. Participants with a flat hearing loss also scored significantly better than those with a sloping hearing loss on several of the sub-tests (number of instruments task, musicality perception task and melody identification task) included in the MPT. The superior performance by those with a more severe hearing loss and/or flat audiometric configuration was however not sensitive to the NFC algorithm being active or inactive and therefore one may rather conclude that performance on these sub-tests may be sensitive to the degree and pattern of hearing loss and not that performance on these sub-tests were influenced by applying a different processing strategy, like NFC.

When one compares the performance of participants with a more severe hearing loss at the mid and high frequencies to the performance of those with a milder hearing loss at the same frequencies, it is clear that an increase in the severity of participants' hearing loss caused a decrease in their performance. With the hearing aids on conventional settings, participants with a more severe hearing loss in the mid frequencies scored significantly higher than those whose hearing loss was less severe on the rhythm discrimination, number of instruments and music-in-noise song identification tasks. Participants with a more severe hearing loss in the high frequencies scored significantly better on the rhythm discrimination, multiple instrument identification, number of instruments and musicality perception tasks. The activation of NFC, however, eliminated this benefit and this serves to confirm that participants with a more severe hearing loss in the mid and high frequency regions may benefit more from NFC for certain tasks. This phenomenon is attributable to the fact that when a hearing loss is more severe, the amount of frequency compression will be more aggressive.

When assessing the influence of the pattern of hearing loss and the application of NFC on participants' performance on the sub-tests included in the MPT, it was clear that when NFC was inactive, participants with a flat hearing loss scored significantly higher than those with a sloping hearing loss on the rhythm identification, discrimination and perception tasks as well as the multiple instrument identification and music-in-noise song identification tasks. This benefit was not observed with the activation of NFC and therefore one may conclude that the application of this algorithm definitely benefits participants with a sloping hearing loss in perceiving musical stimuli. This can be attributed to the fact that, with a sloping hearing loss, more frequencies will undergo compression compared to when the hearing loss is flat. Furthermore, one expects that with a sloping hearing loss the amount of frequency compression will be more aggressive compared to the amount applied with a flat hearing loss and therefore participants with a sloping hearing loss will benefit more from this algorithm being applied (Nyffeler, 2008b:24).

- *Gender*

The literature on musical processing and specific brain hemispheres are often contradictory, but indicates that music is processed in both hemispheres of the brain, although processing of certain aspects of music are highly lateralized (Don *et al.*, 1999:155). As a generalization, melodies and chords appear to be processed holistically by the right hemisphere, whereas analysis involving brief sequences of discrete sounds (e.g. rhythm) depends more on the left hemisphere. Singing, on the other hand, appears to engage the cortex bilaterally if words are involved, but depends mainly on the right hemisphere if they are not (Andrade & Bhattacharya, 2003:285).

From the results obtained, men performed significantly better than women on the pitch discrimination, musicality perception, melody identification and music-in-noise song identification tasks. As it is known that men's brains are, on average, more lateralized than those of women and that most men make stronger use of the right brain hemisphere it is not surprising that men performed better on these tasks (Koelsch, Maess, Grossmann & Friederici, 2003:712). If the melodies included in the familiar melody identification task contained lyrics as well, a different result might have been obtained, because women tend to rely more on both hemispheres when processing information. Koelsch *et al.*, (2003:712) further confirmed that relatively early brain activity elicited by inappropriate harmonies within a musical sequence (e.g. stimuli included in the musicality perception task) is distributed bilaterally over the scalp in females, and lateralized to the right hemisphere in males. Again this explains the superior performance of men in the musicality perception task which include melodies and chords that are known to be processed holistically by the right brain hemisphere.

- *NFC cut-off frequency*

The NFC cut-off frequency was left on the default settings as determined by the fitting software, except for two participants. These participants (participant 13 and 39) complained about the quality of the sound being too bright and tinny and therefore the NFC cut-off frequency was made slightly weaker, which implies a higher cut-off frequency and less high frequencies being compressed. The reason why they might have felt that the sound quality was too bright and tinny was because the default NFC setting was less than 2 kHz and one can assume that these participants were not used to the extensive amount of high frequency amplification they suddenly received with NFC.

- *Data logging*

Data logging values did not differ much for hearing aid use with and without NFC and therefore one can conclude that the use of NFC did not result in a higher preference for participants to wear the hearing aids. The slight differences that exist for participants between the different NFC settings can be attributed to differences and demands in daily routines. All participants wore the hearing aids on average for seven hours or more per day, except for participant 10 who had an average data logging value of five to six hours per day and participant 39 who wore the hearing aids on average four hours per day. Participant 10 indicated that he/she is working from home and only uses hearing aids when consulting with other people, while participant 39 explained that he/she only wore hearing aids when attending social gatherings for example going to church or visiting friends. These participants both indicated that this was their normal pattern of hearing aid use and that it was not because they were wearing new hearing aids for the period of the study.

Leek *et al.*, (2008:523) found that listeners who wore their hearing aids for less than two hours per day tended to report no change in their enjoyment of music. They attributed this to a possibly milder hearing loss that did not distort music in a significant way, or maybe these participants did not use their hearing aids often enough to notice any changes. This was confirmed by the current study as both participant 10 and participant 39 indicated that there was little or no change in their enjoyment of music since using hearing aids. In these cases it can probably be attributed to the fact that they did not use their hearing aids often enough to notice any changes as both of them, and especially participant 39, had a rather severe hearing loss.

6.3 CONCLUSION

Amplification improves adults' hearing related quality of life by reducing the psychological, social, and emotional effects of sensorineural hearing loss, an insidious, potentially devastating chronic health condition if left unmanaged (Johnson & Danhauer, 2006:30). As music is a prevalent art form and social activity, a better understanding of musical perception by hearing aid and cochlear implant users may address issues of user satisfaction in daily functioning (Gfeller & Lansing, 1991:916). Therefore, this study aimed at describing the results obtained with NFC in detail in order to advocate a wider range of hearing aids that may influence the enjoyment of music, thereby increasing the choice and accessibility of hearing health care professionals and their patients that want to enjoy music.

From the discussion it is clear the use of NFC significantly improves hearing aid users' perception of timbre and melody but not pitch. Overall, no significant improvement in their perception of rhythm was observed although performance on some rhythm sub-tests improved significantly. The use of NFC also significantly improved hearing aid users' perception of the musical qualities called overall fidelity, tinniness and reverberance. Although participants experienced the loudness, fullness, crispness, naturalness and pleasantness of music more positive with NFC, these benefits were not significant.

To conclude, the MPT can be used successfully for assessment of music perception in hearing aid users within the South African context and can therefore result in more accountable hearing aid fittings taking place. Furthermore, the use of NFC can definitely increase hearing aid users' appreciation of music and does not influence music perception negatively. Given that still a large percentage of hearing aid users express a loss in enjoyment of music, audiologists should not ignore the possible benefits of NFC, especially if one takes into account that previous research indicated speech perception benefits with this technology.

6.4 SUMMARY

In this chapter the results of the study were explained in detail. All findings were compared with current literature to highlight the value of the results, as this could direct future research regarding music perception and frequency lowering hearing aids.