THE INFLUENCE OF NON-LINEAR FREQUENCY COMPRESSION ON MUSIC PERCEPTION FOR ADULTS WITH A MODERATE TO SEVERE HEARING LOSS

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As partial fulfillment of the requirements for the degree D.Phil Communication Pathology in the Department of Communication Pathology

Faculty Humanities

UNIVERSITY OF PRETORIA

September 2011

BEDANKINGS

Met liefde opgedra aan Pappa en Mamma. Dankie vir al die geleenthede wat julle vir my moontlik maak!

MET OPREGTE DANK EN WAARDERING AAN:

- Die hemelse Vader vir die geleentheid, krag en verstandelike vermoëns om hierdie studie te voltooi.
- Barend vir al jou liefde en ondersteuning.
- Aan alle persone en instansies wat op 'n direkte of indirekte wyse 'n bydrae tot hierdie studie gelewer het.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

OPSOMMING

Rasionaal: Die meeste navorsing met betrekking tot gehoorapparate wat frekwensie verlaag het tot op hede hoofsaaklik gefokus op spraakpersepsievaardighede. Met die verbetering in gehoorapparaattegnologie neem die belangstelling in musiekpersepsie as 'n dimensie wat gehoorapparaatdraers se kwaliteit van lewe kan verbeter, egter toe. Die doel van hierdie studie was tweeledig: Eerstens, om 'n musiekpersepsietoets vir volwasse persone met gehoorapparate te ontwikkel en tweedens, om die invloed van nie-lineêre frekwensiekompressie (NFK) op musiekpersepsie met behulp van die Musiek Persepsie Toets (MPT) wat deur die navorser ontwikkel is te evalueer.

Navorsingsontwerp en steekproef: Fase 1 het die samestelling van die MPT behels en kan beskryf word as ontwerpgebaseerd. In Fase 2 is 'n kwasi-eksperimentale navorsingsontwerp geselekteer. Hierdie fase het die passing van deelnemers (40) met NFK gehoorapparate behels waartydens objektiewe data met NFK aktief en onaktief ingesamel is. In Fase 3 is deelnemers versoek om 'n vraelys te voltooi en sodoende is subjektiewe data oor hul musiekervaring met NFK aktief en onaktief bekom.

Resultate: Resultate het bewys dat normaalhorende volwassenes sowel as volwassenes met gehoorapparate in staat was om al die sub-toetse van die MPT te voltooi. Verder is bevind dat die gebruik van NFK gehoorapparaatdraers se persepsie van toonkleur en melodie statisties beduidend verbeter het, maar nie hul persepsie van toonhoogte nie. In die geheel is geen statisties beduidende verbetering in the persepsie van ritme waargeneem nie, alhoewel prestasie op sommige van die sub-toetse vir ritme wel beduidend verbeter het. Die gebruik van NFK het ook gehoorapparaatdraers se persepsie van die musiekeienskappe bekend as algehele klankgetrouheid, blikkerigheid en weergalming beduidend verbeter. Hoewel deelnemers die luidheid, volheid, duidelikheid, natuurlikheid en aangenaamheid van musiek meer positief met NFK ervaar het, was hierdie voordele nie statisties beduidend nie.

Gevolgtrekking: Die MPT kan suksesvol vir die evaluering van musiekpersepsie by gehoorapparaatdraers in die Suid-Afrikaanse konteks gebruik word en kan daarom daartoe lei dat meer verantwoordbare gehoorapparaatpassings plaasvind. Die gebruik van NFK kan gehoorapparaatdraers se waardering van musiek verhoog terwyl dit nie musiekpersepsie negatief beïnlvoed nie. ‘n Groot persentasie gehoorapparaatdraers ervaar steeds ‘n verlies aan musiekgenot en daarom mag oudioloë nie die moontlike voordele van NFK ignoreer nie, veral nie as daar in ag geneem word dat vorige navorsing met hierdie tegnologie reeds ‘n verbetering in spraakpersepsie uitgewys het nie.

Sleutelwoorde: Gehoorverlies, musiekpersepsie, nie-lineêre frekwensiekompressie, gehoorapparate, frekwensieverlaging, sensories-neurale gehoorverlies, kogleêre dooie areas, musiekgenot, Suid-Afrikaanse konteks

ABSTRACT

Objective: To date, the main focus in frequency lowering hearing aid studies has been in relation to speech perception abilities. With improvements in hearing aid technology, there is a growing interest in musical perception as a dimension that could improve hearing aid users' quality of life. The purpose of this study was two-fold: Firstly, to develop a test of music perception for adult hearing aid users and secondly, to evaluate the influence of non-linear frequency compression (NFC) on music perception with the use of the Music Perception Test (MPT) compiled by the researcher.

Research design and research sample: Phase 1 entailed the compilation of the MPT and can be described as design-based. A quasi-experimental research design was selected to establish the structure of the method employed in Phase 2, which involved the fitting of participants (n=40) with NFC hearing aids. Objective data was obtained with the hearing aids with NFC active and inactive. Phase 3 was characterized by a survey design which elicited subjective impressions of the participants' musical experiences with NFC active and inactive.

Results: Results proved that normal hearing adults as well as adults using hearing aids were able to complete all the sub-tests of the MPT. Furthermore, the use of NFC resulted in a statistically significant improvement in hearing aid users' perception of timbre and melody, but not of pitch. Overall, no statistically significant improvement in their perception of rhythm was observed, although their performance on some rhythm sub-tests improved significantly. The use of NFC also brought about a statistically significant improvement in hearing aid users' perception of the music qualities of overall fidelity, tinniness and reverberance. Although participants experienced the loudness, fullness, crispness, naturalness and pleasantness of music more positively with NFC, these benefits were not statistically significant.

Conclusion: The MPT can be used successfully for assessing music perception in hearing aid users within the South African context and may therefore result in more accountable hearing aid fittings. The use of NFC may increase hearing aid users' appreciation of music whilst not influencing music perception negatively. Given that 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.

Key words: Hearing loss, music perception, non-linear frequency compression, hearing aids, frequency lowering, sensory neural hearing loss, cochlear dead regions, music enjoyment, evidence-based practice, South African context

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Chapter 1

ORIENTATION AND PROBLEM STATEMENT

Chapter aim: In this chapter the formulated research question and the rationale for the study are stated, the relevant terminology is explained and a view of the content and organization of the study are outlined.

1.1 INTRODUCTION

(Retrieved from http://www.sheetmusicplus.com/store/smp_inside.html?cart=3449918755262746&item=4382372&page=01)

The lyrics of the well-known song above are relevant to many people throughout their lives. There certainly are other vital aspects to life, but as Revit (2009:12) postulates: *'Unless some people regularly engage in musical activities, their enjoyment of living seems to decline rapidly'*. Some people may feel that the emphasis placed on music as a precursor to enjoyment of life may not be justified – possibly because they are able to hear music unhindered. For people with a silent disability such as a hearing loss this is certainly true. The fact that hearing loss has often been described as an invisible handicap illustrates why so many people fail to recognize its full impact on their lives (Chartrand, 2008: par. 48). Music is an integral part of our daily life and one is confronted with music on numerous occasions each day. Hearing loss excludes many people from this daily exposure and therefore it is extremely important for individuals with a hearing loss to also have access to music.

High frequency hearing loss is by far the most common audiometric configuration found in individuals fitted with hearing aids (Glista & McDermott, 2008:1; Nyffeler, 2008b:22; Munro, 2007:2; McDermott, Dorkos, Dean & Ching, 1999:1323; Hogan & Turner, 1998:432). In response to this phenomenon a common clinical practice in fitting hearing aids to individuals with a high frequency hearing loss is to provide additional amplification in the higher frequencies (Ross, 2002: par. 1; Turner, 1999:10). However, this is often problematic, since some people may unknowingly present with dead cochlear regions and perceive high frequency amplification as distorted or noise-like in quality (Munro, 2007:3; Vestergaard, 2003:250; Yanz, 2002: par. 31).

High frequency amplification plays an important role in speech understanding because high frequency speech sounds generally convey key information for understanding speech (Ross, 2002: par. 2). An important example is the sound [s]. Its sibilant acoustical energy extends across a wide frequency range, from about 3 kHz to 8 kHz, which may make it difficult or even impossible for people with a high frequency hearing loss to identify (Stelmachowicz, Pittman, Hoover & Lewis, 2002:316). What is true for the [s] sound can also, to a lesser degree, be applied to other consonants (Ross, 2002: par. 2). High frequency amplification is also necessary for the audibility and identification of high-pitched environmental sounds like doorbells, alarms and music (Glista & McDermott, 2008:2). Although the majority of music pitches exists in the lower half of the auditory spectrum with fundamental frequencies at approximately 1 kHz and below, the higher frequency resonances occurring above the fundamental frequency of musical notes assists the listener in distinguishing the sound of one instrument from another (Revit, 2009:14).

Most people with a hearing loss express a need to hear speech optimally (Chasin, 2004:10). However, more and more people with hearing problems are expressing an equal need for their hearing aids to be fitted optimally for listening to music (Chasin, 2005: par. 10). As one may expect, hearing aids were previously designed with speech in mind, not music. Lately, and however long overdue, a concern about the fidelity of music processing by hearing aids has come to the fore (Chasin, 2004:10).

1.2 RATIONALE

A survey conducted in the United States of America estimated that around 10% of the United States' population reported hearing difficulties (Better Hearing Institute, 2009: par. 2). The majority (65%) of these people are younger than 65 years of age (Better Hearing Institute, 2009: par. 4). In the United Kingdom one in five adults has a bilateral hearing loss at a level of 25 dB HL[1] or more, which negatively affects hearing and communication (Davis, 2006:39).

According to the 2001 South African Census (Statistics South Africa, 2001) there is an estimated 1 991 398 people living with a disability of which approximately 313 594 (15.7%) have a hearing loss, rendering hearing disabilities the third largest disability in South Africa, affecting one sixth of its population. The accuracy of statistics regarding the prevalence of hearing disorders in South Africa is questionable due to non-comprehensive diagnosis, incomplete or delayed reporting as well as limited access to health care services. This can be attributed to a lack of identification of hearing disorders and subsequent referral to audiological services by doctors (Davis, 2006:39). These limitations in identifying hearing disorders in South Africa inevitably results in inadequate provision of hearing aids to those who are in need.

The plight of most people with a hearing loss can be alleviated with hearing aids, although four out of five Americans with a hearing loss do not use these (O'Neill, Summer & Shirey, 1999:1). Furthermore, it was found that only approximately 15% of people with a hearing loss currently own hearing aids (Boretzki & Kegel, 2009:1). The main reasons why people do not use hearing aids are related to the cost of hearing aids, vanity, and the stigma associated with wearing them. Furthermore, one third of persons with a hearing loss believe that hearing aids will not be beneficial with the problems they experience, or believe that their hearing loss is only minimal and therefore does not justify the use of a hearing aid (O'Neill *et al.*, 1999:5). These views contribute to the fact that a hearing loss is not viewed as a dramatic health problem requiring urgent intervention (Davis, 2006:42). Due to the reasons mentioned above, it may be assumed that the prevalence of hearing disorders in South Africa is higher than current statistics indicate.

[1]Hearing level (0 dB is average normal hearing for each audiometric test frequency)

Traditionally, statistics on hearing loss have shown the geriatric population to be the most vulnerable (O'Neill *et al.*, 1999:4). However, over the last three decades there has been a sharp increase in the number of younger people with hearing problems. This phenomenon can be ascribed to an increase in environmental noise (O'Neill *et al.*, 1999:4) as well as increased use of personal listening devices and the increase in life expectancy (Eureka Science News, 2008: par. 2). Apart from these factors there are a number of conditions that may lead to the development of a hearing disorder of which the most common in adults is presbycusis[2] (O'Neill *et al.*, 1999:2). The second most common condition is noise-induced hearing loss[3], followed by other possible causes like viral or bacterial infections, ototoxity, birth defects, illness and injuries (Launer & Kühnel, 2001:113; O'Neill *et al.*, 1999:2). Acquired hearing loss is often associated with dysfunction of the outer and inner hair cells of the cochlea while congenital hearing loss may involve abnormalities in many structures and systems other than the outer and inner hair cells of the cochlea, such as abnormal cochlear metabolism, abnormal sodium or potassium concentrations, malformation of the tectorial membrane, collapse or rupture of Reisner's membrane, ossification, demyelization of the auditory nerve and many more (Moore, 2001b:153; Moore, Huss, Vickers, Glasberg & Alcantara, 2000:222).

As mentioned above, cochlear hearing loss often involves damage to the outer and inner hair cells; the stereocilia may be distorted or destroyed, or entire hair cells may die (Moore, 1996:133). The outer hair cells are generally more vulnerable to damage than the inner hair cells and it is suggested that damage in the cochlea at hearing levels above 50 dB HL is not limited to the outer hair cells but also affects the inner hair cells (Huss & Moore, 2005:608; Summers, Molis, Müsch, Walden, Surr & Cord, 2003:133; Ching, Dillon & Katsh, 2001:145). Consequences of outer hair cell loss include elevated absolute thresholds, reduced frequency selectivity[4], difficulties understanding speech (especially in the presence of background noise)

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[2] A gradual age-related reduction in the ability to hear high-pitched sounds (Launer & Kühnel, 2001:113)

[3] Caused by a single exposure to an extremely loud sound or by continuous exposure to sounds at high intensity levels over a period of time (Launer & Kühnel, 2001:113)

[4] Refers to the ability of the auditory system to separate and resolve the components in a complex sound. This is due to the fact that the auditory filters are broader in persons with a hearing loss compared to those with normal hearing (Moore, 1996:136-137).

and loudness recruitment[5] (Kluk & Moore, 2006: par. 5; Turner & Cummings, 1999:54; Moore, 1996:133). Healthy inner hair cells act as transducers, transforming basilar membrane vibration into action potentials in the neurons of the auditory nerve; with a loss of inner hair cells one would experience a reduced efficiency in transduction that leads to elevated absolute thresholds, 'noisy' transmission of information in the auditory nerve as well as no transduction of basilar membrane vibration (Kluk & Moore, 2006: par. 8). Therefore, even if sounds are amplified to well above the threshold for detection, the perception of those sounds by a person with a sensory neural hearing loss is usually abnormal.

From the above it is evident that sensory neural hearing loss can have a substantial negative impact on the life of a person with the hearing loss and his/her family, as it also influences their emotional, physical and social well-being. People with a hearing loss are more likely to report symptoms of depression, anxiety, defensiveness, frustration, impatience, dissatisfaction with life, withdrawal from social activities, increased stress levels, problems with employment and access to information sources (Chartrand, 2008: par. 23; O'Neill *et al.*, 1999:1). One of the reasons for increased stress in individuals with hearing loss is in all likelihood related to the increased incidence of communication failures they experience (Kuk & Peeters, 2008: par. 2). The most pronounced effects of hearing loss are often emotional and psychological in nature and are best described in terms of the psycho-emotional[6] levels of hearing as explained by Chartrand (2008: par. 5):

- *The Primitive (background) level*: This level involves the auditory background of life, much of it indiscernible but nevertheless crucial for one's sense of security in a noisy world (Chartrand, 2008: par. 6). The background noise may be the never ending drone of traffic from a nearby freeway or the cheerful chirping of birds. Any and all of these sounds, as part of our natural or everyday environment, form the ambient backdrop of life and living. Remove these suddenly, and the feeling can be one of isolation, despair, emptiness and insecurity. Changing the intensity of background noise relative to the rest of life's signals (communication) can give rise

[5] Refers to the abnormal perception of loudness that may occur due to hearing loss. The person will hear a relatively soft sound as "soft" but as the loudness level increases, the rate of an increase in loudness with increasing sound level is greater than normal. For sounds with inherent amplitude fluctuations, such as music, this results in an exaggeration of the perceived dynamic qualities as the sound appears to fluctuate more in loudness than it would for a normal hearing person (Moore, 1996:139).

[6] Describing the psychological interaction with the emotions it evokes

to an invited signal level of hearing, bringing constant disruption and emotional disturbance to the unfortunate listener. Most background sounds are in the low frequency domain, the area where the majority of hearing-impaired individuals maintain near-normal hearing function (Chartrand, 2008: par. 8).

- *The Signal (alerting) level*: This level refers to the innate and acquired knowledge about what to approach and what to avoid. Our first exposure to fire, thunder and lightning all represent warning signals that have been learned and stored in the human subconscious. No learning is required to provide emotional responses to these signals (Chartrand, 2008: par. 9). In contrast, we acquire, through experience, a whole new nomenclature of warning and alerting signals – the ring of a telephone, the sirens of emergency vehicles and many more. Whether sound asleep or wide awake, with normal auditory ability no one needs to draw our attention to or interpret these signals for us. They garner involuntary attention to the point of distraction until responded to (Chartrand, 2008: par. 10).
- *The Symbolic (communication) level*: This level of human hearing is most associated with language and verbal communication (Chartrand, 2008: par. 11). So important is this level of perception to one's psychosocial well-being that an average five year old child, with no formal training and little or no ability to read, already demonstrates a working vocabulary of up to 5000 words. Words help us organize patterns of thought, express emotions, and gain or exchange knowledge, as well as assist us in bonding with our fellow beings. A strong correlation between vocabulary size and social, emotional, vocational, and financial development has been demonstrated as the heart of societal development depends heavily on the development of verbal and written language (Chartrand, 2008: par. 12).

In terms of human relationships, educational and vocational progress as well as psycho-emotional well-being, what is the impact of hearing acuity diminishing over time? Firstly, with an advancing hearing loss, we find a role reversal between the primitive and signal levels of hearing as the loss advances. As the backgrounds of life becomes distorted or not clear enough for interpretation at the subconscious level, background noise rises into the signal level where sounds become alarming and distracting. This means that everyday sounds –traffic, machinery, etc – no longer can be shuffled into the background of one's subconscious, but are now unwantedly thrust into the foreground of one's attention (Chartrand, 2008: par. 14). Most common in this development are losses where the high frequencies plummet, making the background-laden low frequencies more audible. Generally, the worse the high frequency loss, the more disruptive the background sounds become and the more aversive they are to one's emotional well-being (Chartrand, 2008: par. 15).

If the primitive level of hearing rises to the signal level, where does the signal level go? Since signal levels may become distorted, softer and possibly not even audible, their usefulness in the scheme of personal security becomes less defined. That is why it can be unsafe to function in the hustle and bustle of life with poor hearing (Chartrand, 2008: par. 18). Within the context of normal healthy human relationships, the preservation of the symbolic level of hearing, or verbal communication, is important to one's social-emotional well-being because hearing adds to the ability to function and advance unfettered within society (Chartrand, 2008: par. 19). The loss of the symbolic level (speech communication) of hearing also means the loss of what is referred to as 'intimate communication'. The loss of intimate communication means the loss of encouragement as well as the nuances of speech that signal empathy or sympathy. As uncorrected hearing loss approaches the stage of severe loss, not only do the softened tones that express empathy and sensitivity disappear for the individual with the hearing loss, but they begin to disappear from his/her own voice as well (Chartrand, 2008: par. 20).

Since hearing loss is 'invisible', those in one's social network may be at a complete loss in understanding what the person with the hearing loss is experiencing (Chartrand, 2008: par. 24). As a result, relationship difficulties more often arise in the lives of individuals with a hearing loss than in people with normal hearing. Divorce rates are higher, as well as estrangement from children and friends. Social dysfunction often leads to higher rates of alcoholism and substance abuse (Chartrand, 2008: par. 25). Labour force participation rates are lower for people with a hearing loss and it is reported that a hearing loss often limits them to a specific type of work and salary level (Eureka Science News, 2008: par. 1). In almost every human challenge, one would expect sufferers to know and recognize their sensory deficiency. The truth is, however, that shortcomings in the hearing and communicative domains are difficult to detect. Instead, life can become a treadmill of embarrassments, feelings of inadequacy, misunderstandings, rationalizations and blame-games until deeper psychosocial barriers prevent the person from seeking help (Chartrand, 2008: par. 26).

From the above it is evident that a hearing loss diminishes quality of life for the affected person and also for his/her family members (Davis, 2006:42). Due to the fact that our quantity of life has increased dramatically over the last century, the concept of quality of life is a popular topic of conversation. Since healthcare has been so successful at increasing life expectancy, efforts are now focusing on ensuring that as we age, we also live well and function well in our day-to-day activities (Chisolm, 2007:10). These aspects highlight the importance of effective amplification, including the amplification of music – as a means of improving the quality of life of persons with a hearing loss (Kuk & Peeters, 2008: par.2).

One of the most challenging hearing loss configurations for audiologists is a precipitously sloping sensory neural hearing loss (Auriemmo, Kuk & Stenger, 2008:50). Not surprisingly, high frequency hearing loss represents the largest number of uncorrected cases (Chartrand, 2008: par. 30). Poor perception of high frequency sounds can cause difficulty in recognizing certain speech sounds, such as the fricative consonants [s] (sun), [t] (task) and [f] (frog) (Glista & McDermott, 2008:2). Almost all of the energy of the consonant [s] is confined to a high frequency range with a peak at 8 kHz or higher. People with a hearing loss make more perceptual errors with [s] than with any other sound in the English language. This is unfortunate, since [s] is not only one of the most frequently occurring sounds in English, but also provides more grammatical information[7] than any other sound (Kortekaas & Stelmachowicz, 2000:645; Boothroyd & Medwetsky, 1992:151).

People with a high frequency hearing loss have difficulty understanding speech because of reduced audibility and, because, for those with severe hearing losses, the individual's proficiency at extracting information from an audible signal is reduced by the need to listen at high sound pressure levels; it is further reduced when sensation level exceeds about 20 dB (Mackersie,

[7] Distinguishes between singular and plural nouns, contractions (it's), 3rd person present tense, present versus past tense and possessive pronouns (Glista & McDermott, 2008:2)

Crocker & Davis, 2004:499; Ching, Dillon & Byrne, 1998:1139; Arehart, King & McLean-Mudgett, 1997:1434). These aspects are described in more detail below.

As speech cannot be understood if it cannot be heard, audibility is undoubtedly a major goal of amplification for people with a hearing loss (Mackersie *et al.*, 2004:499). In restoring audibility, it is often assumed that the listener can extract speech cues over the entire range of speech frequencies. This assumption is true for a person with a mild to moderate hearing loss, but untrue for a severe hearing loss at the high frequencies (Ching *et al.*, 2001:141; Ching *et al.*, 1998:1137). Mackersie *et al.*, (2004:499) observed that the efficiency with which listeners with high frequency hearing losses used audible high frequency information decreased with an increase in hearing loss. Hogan and Turner (1998:439) reported that the contribution of high frequency information to speech recognition was less than is the case in normal hearing listeners once thresholds exceeded 55 dB HL. In both studies, the majority of listeners with 4 kHz thresholds of 80 dB HL or higher were unable to make use of audible high frequency information and some listeners showed a decrease in speech intelligibility when this information was made audible.

The second reason why people with a hearing loss experience difficulty in identifying speech sounds is because they have to listen at high sound-pressure levels (Ching *et al.*, 2001:142). It seems possible that a level distortion factor is needed for any listener because frequency and temporal resolution ability decrease at high presentation levels and hence appear to decrease with hearing loss (Ching *et al.*, 1998:1137).

Furthermore, amplification of high frequencies to high sensation levels for people with severe losses at these frequencies could be detrimental to speech intelligibility. Studies conducted by Ching *et al.*, (2001:142) indicated that for people with a severely sloping hearing loss speech scores deteriorated with increased bandwidth at high sensation levels whereas a definite improvement in speech scores is evident with an increase in bandwidth (from 1.4 kHz to 2.8 kHz) for persons without a severe, high frequency hearing loss. This is also confirmed in another study, showing that for a group of adults with moderate to severe high frequency loss word recognition improved when amplification bandwidth was extended from 1.6 kHz to 3.2 kHz, but no further improvement was obtained when the bandwidth was extended to 6.4 kHz.

All of the above support the proposition that when a hearing loss is extreme at the high frequencies, it was not beneficial to attempt to provide an audible signal at those frequencies (Ching *et al.*, 2001:142). With this information taken into account, provision of high frequency audibility for listeners with a severe high frequency hearing loss is further complicated by the small dynamic range[8] of hearing and acoustic feedback that will limit the amount of usable gain.

However, speech comprehension is not the only ability adversely affected by high frequency hearing loss. High-pitched environmental sounds like alarms, doorbells, telephone ring tones and music may also be difficult to detect and/or identify. Some of these sounds are valuable, mainly because they enhance the quality of a person's overall hearing experience. Additional significance includes the security of being able to quickly and easily recognize high-pitched alarms (Glista & McDermott, 2008:2). Furthermore, for adults, poor perception of high frequency sounds may lead to difficulty in maintaining the quality of their own speech whereas young children will have difficulty in learning to produce speech sounds that contain high frequencies (Glista & McDermott, 2008:1; Kuk, Korhonen, Peeters, Keenan, Jessen & Anderson, 2006:44).

Persons with a high frequency sensorineural hearing loss differ in the benefit they gain from amplification of high frequencies when listening to speech (Baer, Moore & Kluk, 2002:1133). For many years there have been reports suggesting that people with a moderate-to-severe hearing loss in the high frequencies often do not benefit from amplification of the high frequencies, or that their hearing is even worse when high frequencies are amplified (Plyer, Madix, Thelin & Johnston, 2007:150). This may be because sufficient high frequency gain can not be achieved by the hearing aid to reach audibility without feedback occurring (Parent, Chemiel & Jerger, 1997:355). It may also be that the severity of the hearing loss in the high frequency region is so great that it is unaidable (Kuk *et al.*, 2006: par. 1; Arehart *et al.*, 1997:1442). Furthermore, even when sounds can be made audible, they may not be discriminated or recognized (Glista &

[8] Difference between the level of discomfort and the threshold of audibility (Simpson, McDermott & Dowell, 2005:42)

McDermott, 2008:1); this is the scenario for those people who present with cochlear dead regions (Baer *et al*., 2002:1133).

Cochlear dead regions refer to a loss of function of the inner hair cells and/or neurons within specific regions in the cochlea (Moore, 2009:10). The inner hair cells are laid out in a row along the length of the basilar membrane and are the sensory receptors that are responsible for converting acoustic energy into electrical energy by directly stimulating the fibres of the auditory nerve (Ross, 2002: par. 5). Each inner hair cell responds to the vibration of the basilar membrane in the regions where it is located. In return, each region is tuned and responds most strongly to one specific frequency, called the characteristic frequency. The characteristic frequency is low toward the apex of the cochlea and high towards its base (Moore, 2009:10). When the inner hair cells and/or neurons are not functioning at a given place along the basilar membrane, no acoustic information along that region of the basilar membrane is transmitted to the brain (Moore, 2001b:153). Since inner hair cell damage is often associated with outer hair cell damage, the tuning of the basilar membrane, inner hair cells and neurons may be abnormal in an ear with a dead region, even over regions which are not dead (Moore, 2009:10; Moore, 2001a:2).

Often in the case of a cochlear dead region a tone producing peak vibration in that region is detected by off-place listening which means that the tone is detected at a place where the amount of basilar membrane vibration is lower, but the inner hair cells and neurons are functioning more effectively (Markesis, Kapadia, Munro & Moore, 2006:91; Kluk & Moore, 2005:115; Munro, Felthouse, Moore & Kapadia, 2004: par. 1; Cairns, Frith, Munro & Moore, 2007:575). This phenomenon can be explained by normal cochlear dynamics. Each part of the cochlea has a characteristic frequency to which it is tuned. When input sounds are very soft, only a tiny specific region of the outer hair cells in the cochlea is activated. The outer hair cells then energize the corresponding inner hair cells that, in turn, stimulate a specific narrow area of the corresponding nerve fibres (Ross, 2002: par. 8). When exposed to high intensity sounds, the cochlea (actually the basilar membrane within the cochlea) displays a broad excitation pattern and quite a large number of adjacent hair cells may be stimulated. In its normal functioning, the auditory system suppresses signals arriving from locations other than the portion for which it is specifically tuned. On the other hand, when the greatest movement of the basilar membrane occurs in areas where there are cochlear dead regions, then these adjacent areas, with intact inner hair cells, may stimulate auditory nerve fibres and produce an auditory sensation (Ross, 2002: par. 9). Subjectively the audible result of these off-centre locations may be perceived as noise and distortion and they interfere with sound comprehension because they are sending misinformation to the brain regarding the acoustic composition of an incoming sound. Thus, the diagnosis of cochlear dead regions may have implications for candidature for and benefit from amplification (Moore, Killen & Munro, 2003:466; Vickers, Baer & Moore, 2001:149).

Most often a dead region is located toward the basal end of the basilar membrane, which normally responds to high frequencies but it can also occur at the apical end of the cochlea which will result in a low frequency dead region (Moore, 2009:12). The extent of a dead region is defined in terms of its edge frequency, which corresponds to the characteristic frequency of the inner hair cells and/or neurons immediately adjacent to the dead region (Kluk & Moore, 2006:464; Munro, Felthouse, Moore & Kapadia, 2005:470). A dead region in any part of the cochlea can arise as a result of genetic factors, infections, auto-immune disease, aging, noise toxicity or exposure to toxic agents (Taleb, Faulkner & Cunningham, 2006:42). There is no relationship between gender, age and the presence or absence of dead regions (Aazh & Moore, 2007:104). There is also no definitive audiometric pattern associated with dead regions but there are certain audiometric features that are more likely to be present in the presence of a cochlear dead region (Munro, 2007:3).

The presence of cochlear dead regions seems to be rare for audiometric frequencies where the hearing loss is 55 dB HL or less, but becomes increasingly common when the hearing loss is 75 dB HL or more (Moore, 2009:12; Moore 2001a:4). Prevalence data for cochlear dead regions in adults with a sensory neural hearing loss was provided by a study in which 317 adults who attended an Audiology department for the fitting of a hearing aid were assessed. A total of 54% of these adults met the criteria for a dead region at one or more frequencies. Evidence of a dead region when the hearing threshold was 60 dB HL or better was rare, and these researchers concluded that most adults who showed evidence of dead regions had a hearing threshold at, or greater than, 65 dB HL (Munro, 2007:8). This latter study recommended testing for the presence of dead regions when the hearing threshold exceeded 60 dB HL. This recommendation was confirmed by Markesis *et al.*, (2006:97) who found that dead regions are relatively common (85-87%) in people with steeply sloping hearing losses with moderate to profound thresholds at the high frequencies. Moore (2001a:30) also indicated that dead regions are very common with a hearing loss that rapidly increases (more than 50 dB per octave) with increasing frequency. Furthermore, studies by Gifford, Dorman, Spahr and McKarns (2007), Moore (2001a), Vickers *et al.*, (2001), Ching *et al.*, (2001), Turner and Cummings (1999) as well as Ching *et al.*, (1998) clearly show that, when the hearing loss exceeds 55 dB at the high frequencies, amplification of high frequencies is often not beneficial.

The presence of dead regions in the studies mentioned above may vary for a number of reasons for example the cut-off frequency tested as some studies did not test above 4 kHz where dead regions are probably very common (Munro, 2007:10). Furthermore, some of the studies listed above used pre-selected groups of patients and this probably explains the highly variable occurrence of dead regions (Munro, 2007:10). It can be concluded that a 'high risk' group for clinically significant dead regions would be individuals with an extensive hearing loss of 60 dB HL or greater at all frequencies above 1 kHz (Munro, 2007:15).

When a dead region is present, the audiogram will give a misleading impression of the degree of hearing loss for a tone of which the frequency falls in the dead region (Moore, 2001a:3). Effectively, the 'true' hearing loss in a dead region is infinite, but the audiogram may sometimes indicate only a moderate one. A high frequency dead region is usually associated with a severe to profound hearing loss at the high frequencies and the audiogram is often steeply sloping (Moore, 2001a:6). Dead regions may, however, occur even when the audiogram is not steeply sloping; therefore, the slope of the audiogram does not serve as a reliable feature for assessing the presence or absence of dead regions (Moore, 2001a:7). An even more difficult task is to define the extent of any dead region by only looking at an audiogram (Moore, 2001a:7).

Accurate diagnosis of dead regions cannot be achieved using the audiometric threshold at the test frequency alone (Aazh & Moore, 2007:103; Mackersie *et al.*, 2004:499). The Threshold Equalizing Noise test (TEN) has been used to identify cochlear dead regions and involves the measurement of pure-tone thresholds in the presence of broadband noise spectrally shaped to produce equal masked thresholds across frequencies (Moore, 2009:16). Dead regions at specific frequencies are indicated by elevated thresholds in the presence of this masking noise (Mackersie *et al.*, 2004:500). The TEN test was found to detect a dead region 95% of the time (Moore, 2009:16). It can be used clinically to gain insight into the likely benefit to be obtained from providing a hearing aid, also to provide information that may help in the selection of an appropriate hearing aid and furthermore to assist in assessing candidacy for hearing aids and cochlear implants (Moore, 2004:107; Moore *et al.*, 2003:473).

Although the TEN test serves as a useful tool for detecting dead regions, it does not precisely define the edge frequency (Munro, 2007:6). A solution is to identify the edge frequency using psychophysical tuning curves (PTCs). A PTC shows the level of a narrowband masker required to mask a low level signal, plotted as a function of masker centre frequency. The lowest masker level required to mask the signal defines the tip of the PTC – this is the frequency at which the masker is most effective. In normal hearing listeners the tip of the PTC usually lies close to the signal frequency. In listeners that have a hearing loss without a dead region, the tip of the PTC is usually broader but still close to the signal frequency. In cases where the signal frequency is within a dead region the tip will be shifted away from the signal frequency. The tip of the PTC will be shifted to the frequency which corresponds to the place on the basilar membrane where the signal is being detected. This identifies the edge of the dead region. When the tip of the PTC is shifted towards a lower frequency, this indicates a high frequency dead region and vice versa. Traditionally PTC measurements are time consuming, as each one requires measurement of many masked thresholds in order to define the frequency at the tip (Munro, 2007:7).

There are several theoretical reasons why people with dead regions may extract little or no information from frequency components of speech that fall within a dead region, even when those components are sufficiently amplified to make them audible. These reasons include (Moore, 2001a:20; Vickers, Moore & Baer, 2001:1172):

- The frequency components are received through the 'wrong' place in the cochlea. For example, if there is a high-frequency dead region, amplified high-frequency components will be detected and analyzed via the frequency channels that are tuned to lower frequencies. This mismatch between frequency and place may lead to difficulty in interpreting the information derived from the high frequencies.

- If the components falling in the dead region are amplified sufficiently to make them audible, they will be detected and analyzed via the same neural channels that are used for other frequencies, and this may impair the analysis of those other frequencies. For example, if there is a low-frequency dead region, the amplified low-frequency components will be detected and analyzed through the same neural channels as are used for the medium and high frequencies. Since speech is a broadband signal, usually containing components covering a wide frequency range, this may lead to some form of 'information overload' in those channels.
- Information in speech, such as information about formant frequencies, may partly be coded in the time patterns of the neural impulses. The analysis of temporal information may normally be done on a place-specific basis. For example, the neural machinery required to 'decode' temporal information about frequencies around 1 kHz may be restricted to neural channels with characteristic frequencies close to 1 kHz. When there is a mismatch between the frequencies of speech components and the place where they are detected, the temporal decoding mechanisms required to analyze those speech components may not operate effectively.

Pure tones are often described as sounding highly distorted or noise-like when they fall in a dead region (Munro, 2007:3; Moore, 2001a:24). Furthermore, compromised inner hair cell integrity, as defined by the identification of dead regions, has been associated with reduced accuracy of pitch perception, reduced tonality of pure tones, and reduced utility of high frequency speech information in speech recognition (Ricketts, Dittberner & Johnson, 2008:169). Frequency discrimination measurements also suggest that frequency tones falling in a dead region do not evoke a clear pitch or can have an abnormal timbre (McDermott & Dean, 2000:353). Specifically, the studies of pitch perception which included people with dead regions indicate the following (Moore, 2001a:27):

- Pitch matches (of a tone with itself, within one ear) are often erratic, and frequency discrimination is poor for tones with frequencies falling in a dead region. This indicates that such tones do not evoke a clear pitch sensation.

- Pitch matches across ears of subjects with asymmetric hearing loss, and octave matches within ears, indicate that tones falling within a dead region sometimes are perceived with a near 'normal' pitch and sometimes are perceived with a pitch distinctly different from 'normal'.
- The shifted pitches found in some subjects indicate that the pitch of low frequency tones is not represented solely by a temporal code. It is possible that there needs to be a correspondence between place and temporal information for a 'normal' pitch to be perceived.

While amplification may allow the frequencies corresponding to the dead region to be detected via spread of excitation, this does not necessarily improve speech recognition for frequencies that fall inside the dead region (Moore, 2009:16, Launer & Kühnel, 2001:118). Thus, the diagnosis of the presence and extent of cochlear dead regions may have implications for candidature for and benefit from amplification as their needs differ from persons with no dead regions[9] (Cairns *et al.*, 2007:575; Munro, 2007:1). This may therefore play an important part in hearing aid success (Bentler, 2006:91).

The main goal of a hearing aid fitting is to provide audibility over a broad frequency spectrum with a variety of input levels (Bagatto, Scollie, Glista, Parsa & Seewald, 2008: par. 1). For listeners with high frequency sensorineural hearing loss, this goal may for several reasons be difficult to meet with amplitude compression technology. Firstly, this technology is limited in its ability to provide the appropriate amount of gain for soft, high frequency sounds. Conventional amplification may not provide sufficient audibility for consonants such as [s], [f] and [t] for sloping high frequency hearing losses (Glista, Scollie, Bagatto & Seewald, 2008:1). If suitable gain is achieved in the high frequency region, acoustic feedback may occur when the instrument is worn by the listener (Glista *et al.*, 2008:1). Feedback[10] is a long-standing problem in hearing aids (Freed & Soli, 2006:382) and when occurring, the application of a feedback management strategy and/or gain reduction is a common solution (Flynn & Schmidtke Flynn, 2006:58). Additionally, conventional hearing aids have a narrow output bandwidth and do not consistently make high frequency sounds audible for listeners (Bagatto *et al.*, 2008: par. 1). These factors

[9] For persons without dead regions, restoration of audibility through high frequency amplification usually leads to improved intelligibility (Moore *et al.*, 2003:466; Baer *et al.*, 2002:1133; Stelmachowicz, 2001:174).

[10] Feedback results from the repeated amplification (and growth) of a particular sound through an amplification circuit (Merks, Banerjee & Trine, 2006: par. 2).

limit the audibility of important high frequency sounds, especially for individuals with sloping and/or severe to profound hearing losses.

Despite the shortcomings of traditional amplification, few alternative rehabilitation options have been available to listeners with relatively good low frequency hearing and precipitous high frequency hearing loss (Gifford *et al.*, 2007:1195). Due to the fact that a sensory neural hearing loss is not remediable with medication or surgery (Hogan & Turner, 1998:432), a hearing aid still is the preferred form of treatment because amplification is non-invasive and low-risk with considerable potential benefits (Johnson & Danhauer, 2006:30). Another possibility is cochlear implants, which provide high frequency information through direct electrical stimulation of the spiral ganglion cells in the basal region of the cochlea. Although this treatment option involves a risk of damaging neural tissue in the apical region of the cochlea, multiple studies have demonstrated that an electrode array can be inserted to the cochlea without destroying residual low-frequency hearing and therefore can be an effective and safe treatment option (Gifford *et al.*, 2007:1195; Kuk, Peeters, Keenan & Lau, 2007:60, McDermott, 2004:49). Not all persons with such a hearing loss are however candidates for cochlear implantation (Clark, 2003:551) or can afford a cochlear implant due to the financial costs (Clark, 2003:769; DeConde Johnson, Benson & Seaton, 1997:92). Especially in South Africa that is characterized by high levels of unemployment and poverty (Statistics South Africa, 2001), a hearing instrument can be a more economical alternative for a cochlear implant.

In their search for technology that would provide their hearing aid wearers with the most complete picture, dispensing professionals may need to rethink how hearing aids amplify speech and other sounds, how the amplified signal is delivered to the impaired ear and how to assess hearing aid benefit (Davis, 2001:37). If this is taken into account, another intervention option emerges. This involves the use of frequency lowering amplification (Gifford *et al.*, 2007:1195) where high frequency sounds are processed and delivered to the lower frequencies, where people are likely to have more residual hearing (Ross, 2000: par. 2; McDermott *et al.*, 1999:1323). In extreme cases, where there is little or no residual hearing at relatively high frequencies, frequency lowering is probably the only way of enabling hearing aid users to detect high frequency sounds (McDermott *et al.*, 1999:1323).

Many researchers over the years have suggested the possibility of frequency lowering as a means of making speech sounds audible to patients with dead regions (Moore, 2009:16; Bagatto *et al.*, 2008: par. 2; Moore & Alcantara, 2001:277). There are, however, several potential problems posed by frequency lowering (Moore, 2001a:30). Firstly, there is likely to be a limit to the amount of information that can be 'squeezed' into the limited region of residual hearing since there is a danger of 'overloading' that region. Secondly, the lowered information is presented to the 'wrong' place in the cochlea which may lead to difficulty in interpreting the information (Moore, 2001a:30; Moore *et al.*, 2000:206) and require an extended learning period to make effective use of information from the lowered frequencies. Thirdly, when background noise is present, portions of the noise that were previously inaudible, may be lowered to a frequency region where it is more audible, and this may offset any advantage that would otherwise be gained from the lowering (Moore, 2001a:30).

Various signal processing strategies have emerged to allow frequency lowering so that information can be more easily accessed by the listener. At first, target beneficiaries of this technique were people with a severe-to-profound loss in the high frequencies who could not benefit from conventional amplification (Kuk *et al.*, 2006: par. 3), but with improvements in this technology other degrees of hearing loss are also considered. There are three main types of frequency lowering strategies available at present; these are summarized in Table 1-1:

Table 1-1: Frequency lowering strategies available at present

STRATEGY	SIGNAL PROCESSING
Proportional frequency compression often referred to as 'frequency transposition'	Hearing aids that utilize proportional frequency compression shift the entire sound signal downwards by a constant factor, thus preserving the natural ratios between the frequency components of speech (Jerger, 2009:288; Turner & Hurtig, 1999:884).
Linear frequency transposition	The linear frequency transposition strategy only shifts the high frequency information of a sound signal downwards by a fixed amount and not the whole frequency spectrum (Jerger, 2009:288; Kuk *et al.*, 2006).
Non-linear frequency compression	Hearing aids with non-linear frequency compression technology compress only the high frequencies of a sound signal in increasing degrees. This is determined by a cut-off frequency calculated according to the person’s audiometric thresholds. All frequencies below the cut-off frequency are amplified in a normal manner (Bagatto *et al.*, 2008: par. 2; Glista & McDermott, 2008:2).

Mixed results were obtained from adult studies using proportional frequency compression. Turner and Hurtig (1999:884) found significant improvements in speech recognition for many of their participants with a hearing loss, but this was not confirmed in a similar study by McDermott and Dean (2000:359), who found that proportional frequency compression did not improve the speech perception of adults with sloping, high frequency hearing losses. In another study, Simpson, Hersbach and McDermott (2005:289) found that this type of frequency lowering improves the recognition of monosyllabic words but again this was not confirmed as a later study found no significant benefit when proportional frequency compression was used to assess speech recognition (Simpson, Hersbach & McDermott, 2006:629).

Linear frequency transposition studies have also produced mixed results. Rees and Velmans (1993:58) found that children demonstrated a marked benefit from linear frequency transposition but Robinson, Baer and Moore (2007:305) found that although this frequency lowering strategy increased the recognition of affricates and fricatives in adults, in some cases it was at the expense of other speech sounds. A more recent development of linear frequency transposition did however demonstrate improved recognition of high frequency sounds (Kuk *et al.*, 2006:45) and resulted in better perception of consonants (Kuk *et al.*, 2007:63).

Non-linear frequency compression is a recent frequency lowering scheme that has shown some promising speech related results for adults and children with a severe to profound hearing loss. With the use of this frequency lowering strategy, significant improvement in at least one speech recognition task was obtained, as well as improvement in the production of high frequency speech sounds (Bagatto *et al.*, 2008: par. 7). Currently more studies are in progress to validate the efficacy of this technology. This information will be discussed in more detail in Chapter 3.

When comparing the different approaches, large differences in manner of implementation resulting in differences in sound quality and potential speech understanding benefit are apparent and should be considered when evaluating the reported results. It is however evident from the above that most research on frequency lowering strategies focused on improvements in speech intelligibility, without any mentioning of the potential influence of these strategies on music perception (Scollie, Glista, Bagatto & Seewald, 2008:8) – and this while an integral part of people's daily lives entails listening to music and other non-speech sounds.

Music can be defined as humanly organized sound, formed intentionally, into a recognizable aesthetic entity directed from a maker to a known or unforeseen listener, publicly through the medium of a performer, or privately by a performer as listener (Godt, 2005:84). While enjoyment is certainly one of its main purposes, music also serves as a medium that models social structures and facilitates the acquisition of social competence by young people (Cross, 2006:80). Music can legitimately be regarded as part of the same human communicative toolkit as language when viewed from the perspective of pragmatics. Its semantic indeterminacy, together with its capacities to entertain, provides a potent medium for human interaction (Cross, 2006:80) as music is often inseparably associated with some event, activity, or behaviour (Godt, 2005:83). With this taken into account, the majority of people wearing hearing aids complain of the reduced sound quality of music heard through their personal amplification (Chasin, 2003b:36). This may be due to the fact that most hearing aids are designed with the focus on hearing speech sounds and not music; this is problematic since there are various major differences between music and speech. These differences are presented and discussed in Table 1-2.

Table 1-2: Differences between music and speech

MUSIC	SPEECH
Origin Music can be generated by a wide range of instruments and varies dramatically depending on playing style, type of music, and number of musical instruments (Chasin, 2004:10).	Speech comes from a human sound generator that is remarkably similar from person to person (Chasin, 2005: par. 6). As it is produced by the human vocal tract it is generated by a limited number of articulators including the nose, tongue position, and lip configuration.
Loudness Music is louder than speech (Chasin & Schmidt, 2009:32). Depending on the music played or listened to, various musical instruments can generate sounds from very soft (20-30 dB SPL) to loud (Chasin 2007: par. 3). Even quiet instrumental music can be in excess of 90 dB SPL with sustained levels of higher than 105 dB SPL. This is true for both classical and popular forms of music (Chasin & Schmidt, 2009: 32). The dynamic range of music as an input to a hearing aid is therefore in the order of 100 dB (Chasin 2010:27).	Because all speech derives from the human tract, meaning similar human lungs imparting similar sub-glottal pressures to drive the chords, the potential intensity range is well defined and also quite restricted to approximately 30-35 dB (Chasin, 2007: par. 3). The most intense components of speech are the low back vowels e.g. [a] as in f<u>a</u>ther. At the level of the listener's ear these sounds, even when shouted, rarely exceed 85 dB SPL (Chasin, 2003b:36). Speech at average conversational levels is typically in the 65-70 dB SPL range with intense components ranging up to the 85 dB SPL (Chasin 2010:27). Loud speech or screaming can be slightly more intense but typically only in the lower frequency regions. The dynamic range of speech as an input to a hearing aid is therefore in the order of 30-35 dB (Chasin, 2007: par. 3).
Variability Music, in contrast to speech, is usually more intense, highly variable and contains very quick changes from soft to loud (Chasin & Russo, 2004:36: Chasin, 2003a: par. 18). Unlike speech which is usually 'loud-soft-loud….' because loud vowels are frequently followed by soft consonants, followed by louder vowels, music is not predictable (Chasin, 2005: par. 7). Music can derive from many sources such as the vocal tract, various music instruments and also any number of musical instruments (Chasin, 2007: par. 2). Any of these sources can be amplified or un-amplified. Even if un-amplified, the music may be low or high in intensity, depending on the musical instruments included (Chasin, 2007: par. 2). There is simply no music 'target' when programming hearing aids as there is for amplified speech (Chasin, 2007: par. 2).	Speech is relatively well defined with well established and predictable perceptual characteristics – most of its loudness comes from the low pitched vowels and most of the speech clarity comes from the higher pitched consonant sounds (Chasin & Russo, 2004:36).
Crest factor A crest factor refers to the difference between the average level of a sound and the peak sound. Music, which is usually generated by hard-walled, minimally damped instruments, has a crest factor of 18-20 dB (Chasin, 2004:10). This has implications for setting the compression circuit as music may cause compression systems to enter the non-linear phase at a lower intensity than would be appropriate for the individual (Chasin, 2007: par. 4).	Since speech is generated by the vocal tract, the output spectrum is highly damped (Chasin, 2004:10). Before a spoken word is heard, the vocal energy passes by the soft tongue, soft cheeks and lips and a nasal cavity full of soft tissue. The soft tissue dampens the sound to such a degree that the peaks are generally only 12 dB more intense than the average intensity of speech (Chasin 2007: par. 4). For a given hearing loss, a musical input would require less gain in order to have the same output as a typically less intense speech input (Chasin, 2003a: par. 15). The crest factor for speech is about 12 dB.

MUSIC	SPEECH
Important frequency region Although the highest orchestral pitches may reach 4 kHz-5 kHz, the majority of music pitches exist in the lower half of the auditory spectrum, with corresponding fundamental frequencies at approximately 1 kHz and below (Revit, 2009:14). For example, 63 of the notes of an 88-key piano keyboard have pitches with fundamental frequencies below 1 kHz. In the human singing voice, almost all of the pitches have fundamental frequencies below 1 kHz. The highest pitch, designated 'soprano' (C6), has a corresponding fundamental frequency of 1046.5 Hz (Revit, 2009:14). At the low-pitch end, the lowest normal note of a guitar has a fundamental frequency of 82.4 Hz. For these low notes the pitch is perceived even if the fundamental is missing. However, the fundamental is often important for hearing the balance of one note against another, as well as for hearing the natural warmth and fullness of low-pitch notes (Revit, 2009:14). The higher frequencies are of course also important for music (Revit, 2009:14). The sustained notes and percussion of music may be considered correlates of the vowels and consonants of speech. With speech, vocal tract resonances (formants), which occur at frequencies well above the fundamental frequency (pitch) of a voice, help the listener to distinguish one vowel from another. Similarly, resonances occurring above the fundamental frequency of musical notes help the listener to distinguish the sound of one instrument from another (Revit, 2009:14). In speech, the frequencies of the formant resonances are determined largely by manipulations of the volumes of air in the supra-glottal vocal tract. In musical instruments, the resonances are usually determined by fixed geometric properties of the instrument (e.g. tubing and pipe lengths), creating emphasis at one or several of the upper harmonics of a given note (Revit, 2009:14). Generally, the highest important vowel formant, F3, can be centred as high as about 3 kHz. Instrumental harmonic resonances may occur in that same range, but they often extend much higher. For example, the violin (which is very rich in harmonics), often has significant harmonics above 5 kHz (Revit, 2009:14). Most of the pitches of musical notes fall at or below 1 kHz and therefore sufficient adjustability should be available for fine tuning, essentially balancing those pitches. Also, as instrumental resonances occur at higher frequencies, fine tuning may also be required for smooth responses in the upper frequencies.	The most important spectral range is above 1 kHz, meaning essentially that the frequencies at or above 1 kHz contributes the highest percentage of the importance of a speech signal for intelligibility (Revit 2009: 12). Therefore, it's not uncommon that the main focus of hearing aid fitting programs is given to fine-tuning the frequency response at or above 1 kHz (Revit, 2009:12).

Table 1-2 above addresses the differences between music and speech as stimuli to hearing aids. There are however, also shared phenomena in the processing of speech and music. The best example of such commonalities is perhaps that both require a broad bandwidth and the smoothest response possible, given the constraints of modern technology. This not only helps to improve sound quality, but optimizes the transient response to such an extent that amplified music will be a better replication of the original input (Chasin, 2006:22). It is however evident that a hearing aid which performs well with speech signals may not perform well with music, the reason being that musical signals are much more variable than speech and our perception of music is more sensitive to distortion (Ryan, 2009:38; Chasin, 2005: par. 7). It is important to understand the differences between music and speech in order to understand the programming of internal algorithm changes necessary for music as an input to a hearing aid (Chasin, 2005: par. 6).

Guidelines have been provided for the optimal hearing aid for music lovers and include (Chasin, 2006:22; Chasin & Russo, 2004:45; Chasin 2004:16; Chasin, 2003b:41):

- A high input-limiting level of at least 105 dB SPL
- Wide dynamic range compression (WDRC) to prevent the compression circuit from entering its non-linear phase prematurely (Chasin, 2003b:40) with a higher threshold knee-point (TK) than prescribed for speech. Compression characteristics for speech are set based on the crest factor of speech which is around 12 dB (Chasin, 2007: par. 13). For speech, wide dynamic range compression systems function to limit overly intense outputs and to ensure that soft sounds are heard as soft sounds, medium sounds as medium sounds, and intense sounds as intense sounds (but not too intense). In short, these systems take the dynamic range of speech (30-35dB) and alter it to correspond with the dynamic range of the person with a hearing loss. The dynamic range of music is typically 50 to 70 dB greater than that of speech. Having said this, it turns out that, clinically, no major changes need to be made since the more intense components of music are just in a different part of the input-output curve of the compression function (Chasin 2007: par. 13). The difference lies in whether the compression system uses a peak detector. If the hearing aid utilizes a peak detector to activate the compression circuit, the knee-point should be set about 5-8 dB higher for a music program than for speech; this is related to the larger crest factor of music (Chasin 2007: par. 13).
- A single channel system (or multi-channel system in which each channel has similar compression ratios). The rationale behind a single channel is that in music, unlike speech, the balance between the lower frequency fundamental energy and the higher frequency harmonic energy is crucial for the perception of optimal sound quality (Chasin, 2003b:40). Therefore it is necessary to use a single-channel hearing aid that maintains this balance. In sharp contrast to hearing speech, one channel, or many channels with the same compression ratios and knee-points, appears to be the appropriate choice for listening to music (Chasin 2007, par. 12). Unlike speech, the relative balance between the lower-frequency fundamental energy and the higher-frequency harmonics is crucial for most types of music. High-fidelity music is related to

many parameters, one of which is the audibility of the higher frequency harmonics at the correct amplitude. Poor fidelity can result from the intensity of these harmonics being too low or too high. A multi-channel hearing aid that uses differing knee-points and degrees of compression for various channels runs the distinct risk of severely altering this important low-frequency (fundamental)/high frequency (harmonic) balance. Subsequently, a 'music program' within a hearing aid should be one channel or equivalently, a multi-channel system where all compression parameters are set in a similar fashion (Chasin 2007: par. 12).

- Omni-directional settings. In most cases, there is fairly good signal-to-noise ratio for the music versus noise, so reducing noise with directional microphones are not compensated in such a manner that there is a significant low-frequency loss of transduced sound. While this may be beneficial for speech in some environments, it unnecessarily removes valuable musical information.
- Less low-frequency amplification for bass instruments such as the cello. Phonetic versus phonemic perceptual requirements refers to the difference between what is actually heard – the physical vibrations in the air (phonetic) as opposed to the perceptual needs or requirements of the individual (phonemic) (Chasin 2007: par. 5). For speech, despite the fact that for all languages of the world, the long-term speech spectrum contains most of its energy in the lower-frequency region and less in the higher frequency region (its phonetic manifestation); the clarity derives from the mid- and high frequency regions. This mismatch between energy (phonetic) and clarity (phonemic) is complex (Chasin 2007: par. 5). In contrast to speech, some musicians need to hear the lower-frequency sounds more than others, regardless of the output (phonetics) of the instrument (Chasin 2007: par. 6). A clarinet player, for example, is typically satisfied with the tone only if the lower frequency inter-resonant breathiness is at a certain level, despite the fact that the clarinet can generate significant amounts of high-frequency energy. This is in sharp contrast to a violin player who needs to hear the magnitude of the higher frequency harmonics before he/she can judge the sound to be good. The clarinet and violin both have similar energy spectra (phonetics) but dramatically differing uses of the sound (phonemics) (Chasin 2007: par. 6).
- Disabled or minimized noise reduction and feedback management systems as some hearing systems can confuse music with noise and/or feedback and will therefore reduce its intensity. In most cases, since spectral intensity is greater for music than for speech, feedback is not an

issue and therefore, if at all possible, disabling any feedback reduction system would be the optimal approach for listening to or playing music (Chasin, 2007: par. 15). As with feedback-reduction systems, it would be best to disable the noise reduction system when listening to music. Typically, the signal-to-noise ratio is quite favourable making noise reduction unnecessary (Chasin 2007: par. 16). However, for some hearing aids, the noise reduction system cannot be disabled; since the primary benefit of noise reduction systems seems to be in improving listening comfort rather than reducing noise, choosing an approach for music that has a minimal noise-reducing effect may be beneficial for a music program (Chasin 2007: par. 16).

Historically, the primary concern for hearing aid design and fitting was optimization for speech input (Chasin & Russo, 2004:35). However, other types of inputs are now increasingly being investigated, especially music as input signal to a hearing aid. Not only is the technology for music input still in its infancy, but the research and clinical knowledge and understanding of what musicians and music lovers need to hear is also still in its early stages (Chasin & Russo, 2004:35). Many manufacturers do state that the music program of their digital hearing aid should be as simple as possible, without any of the features available for speech input programs. This may or may not be the case for music and, more research is clearly required in this area (Chasin & Russo, 2004:45).

1.3 PROBLEM STATEMENT AND RESEARCH QUESTION

All of the above-mentioned studies focused on speech as input stimuli for non-linear frequency compression hearing aids and there is no indication of how non-linear frequency compression will influence the perception of music (Scollie *et al.*, 2008:8). Most people with a hearing loss express a need to hear speech optimally, but increasing numbers of people with hearing problems are expressing an equal need for their hearing aids to be fitted optimally for listening to music (Chasin 2005, par. 10; Chasin, 2004:10).

While hearing aids have improved dramatically, they are not yet perfect (Chasin, 2008: par. 1). Various approaches have been followed by the hearing aid industry to optimize a hearing aid or a program within a hearing aid for music. Some manufacturers have sought to reduce the low frequency amplification and output, others have tried to increase the gain and output (Chasin, 2003b:36). Still others have employed a strategy of increasing mid-frequency gain and output to optimize the long term spectrum of music. These approaches have met with only limited clinical success (Chasin, 2003b:36) and therefore a vast opportunity exists for evaluating music listening with non-linear frequency compression technology.

Due to the complex nature of music, amplification of musical stimuli poses a challenge to audiologists. Studies of frequency lowering hearing aids and music seem to be very limited, but non-linear frequency compression may be beneficial for adults who love to listen to music. Stelmachowicz (2001:174) stresses that a distinction should be made between a decrease in performance and a failure to observe an improvement when working with persons with a hearing loss. Non-linear frequency compression may not provide much benefit for the perception of music or may improve the quality of music for hearing aid users. Therefore, the need exists for research data on non-linear frequency compression technology and music perception. Thus, in light of the discussion above, the following question arises:

Does non-linear frequency compression affect the perception of music by adults presenting with a moderate to severe hearing loss, and if so, in which way?

As can be seen from the above, music is highly complex and therefore music perception with hearing aids is difficult to assess. Furthermore, no standard test of music perception exists (Wessel, Fitz, Battenberg, Schmeder & Edwards, 2007:1) and the few music perception tests that are commercially available are advanced and designed to examine the skills of individuals with formal musical training (Don, Schellenberg & Rourke, 1999:158). Therefore, in order for the current research to answer the above-mentioned question, a music perception test for the assessment of music perception in adult hearing aid wearers had to be compiled.

In order to address the research question comprehensively, a research project was implemented that consisted of a theoretical as well as an empirical component. The basic structure of this research project is provided in section 1.6.

1.4 CLARIFICATION OF TERMINOLOGY

Short clarifications are provided for some of the audiological and medical terms that are referred in the research project. These terms are presented in alphabetical sequence:

- **Adult:** An adult is a fully developed and mature person (Collins, 1989:14). Legally, an adult is considered as a person who by virtue of attaining a certain age, generally eighteen, is able to manage his or her own affairs (Brink, 1997:520). The age specified by the law, the 'legal age of majority', indicates that a person acquired full legal capacity to be bound by various contracts/documents that he or she enters into with others and to commit to legal acts such as voting in elections and entering marriage. For the purpose of this study, the age of eighteen was accepted as the entering age into adulthood and therefore no persons under the age of eighteen participated in this study.
- **Amusia:** The inability to recognize musical tones or rhythms or to reproduce those (Cooper, Tobey & Loizou, 2008:618).
- **Auditory cortex:** Auditory area of the cerebral cortex located on the transverse temporal gyrus (Heschl's gyrus) of the temporal lobe (Stach, 2003:30).
- **Auditory fusion:** Refers to the size of the temporal interval between two events that is required for them to be perceived as two separate events rather than fused as one. Thus, auditory fusion thresholds represent a psychophysical indicator of temporal resolving power for central sensory information processing (Rammsayer & Altenmuller, 2006:38).
- **Bandwidth:** Refers to the range of frequencies (lower to upper) being processed by a communication channel, but often used loosely to describe the upper frequency of the signal of interest, assuming that the lower frequency is negligibly small. Widening the bandwidth means increasing the frequency range, and thereby enabling more information to be delivered through the channel (McDermott, Baldwin & Nyffeler, 2010:34). Even though the normal young ear has an upper frequency limit of hearing of about 20 kHz, digital hearing aid amplifiers are generally limited by designers to a bandwidth of about 8 kHz in order to prevent aliasing (Agnew, 2000:40).
- **Characteristic frequency:** The frequency to which an auditory nerve fibre is most sensitive (Preminger, Carpenter & Ziegler, 2005:601).

- **Cochlear dead regions:** An area in the cochlea where inner hair cells are non-functioning, preventing transduction of sound in that region (Moore, 2001b:153).
- **Cochlear nucleus of brainstem:** A collection of neuron cell bodies in the lower brain stem (pons) that synapses with fibres from the auditory (VIII) cranial nerve leading from the cochlea (Mueller & Hall, 1998: 914).
- **Compression knee-point:** The minimum input decibel level at which compression circuitry is activated in a hearing aid, also known as compression threshold (Stach, 2003:64).
- **Compression ratio:** The decibel ratio of acoustic input to amplifier output in a hearing aid (Stach, 2003:64). In the case of non-linear frequency compression technology this refers to the amount of compression applied to frequencies above the cut-off frequency (McDermott, 2010:3).
- **Cut-off frequency:** In the case of non-linear frequency compression this refers to the point above which the frequency compression and lowering is applied (McDermott, 2010:3).
- **Decibel (dB)**: One tenth of a bel that represents the unit of sound intensity on a logarithmic scale (Brink, 1997:94).
- **Decibel hearing level (dB HL)**: A decibel scale referenced to accepted standards for normal hearing (0 dB is average normal hearing for each audiometric test frequency) (Mueller & Hall, 1998:918).
- **Decibel sound pressure level (dB SPL)**: A decibel scale referenced to a physical standard for intensity (Mueller & Hall, 1998:918).
- **DPOAE:** Distortion product oto-acoustic emissions are responses generated when the cochlea is stimulated simultaneously by two pure tone frequencies of which the ratio is between 1.1 to 1.3 (Plante & Beeson, 1999:38).
- **Dynamic range:** Difference in decibel (dB) between hearing threshold and discomfort level (Mueller & Hall, 1998:922).
- **Frequency:** The number of cycles occurring per unit of time, or which would occur per unit of time if all subsequent cycles were identical with the cycle under consideration, is the frequency. The frequency is the reciprocal of the period. The unit is the Hertz (Hz) or cycle per second (cps) (Mueller & Hall, 1998:926).
- **Frequency compression:** In terms of acoustics, compression is defined as a portion of the sound-wave cycle in which particles of the transmission medium are compacted. In hearing

aid circuitry it refers to nonlinear amplifier gain used either to limit maximum output (compression limiting) or to match amplifier gain to an individual's loudness growth (dynamic-range compression) (Stach, 2003:62), but is also used in frequency compression hearing aids. A frequency compression hearing aid is a hearing device that is designed to compress higher frequency energy into lower frequency amplification, especially for use in patients with dead regions at high frequencies (Nyffeler, 2008b:22). By compressing and lowering otherwise inaudible high frequencies into an adjacent lower frequency area, the audible range is extended.

- **Frequency lowering:** A general term that refers to signal processing that lowers high frequency sounds to lower frequencies (Ross, 2005: par. 5).
- **Frequency transposition:** A hearing aid with frequency transposition shifts the signal down the frequency axis by a fixed number (Bagatto *et al.*, 2008: par. 3), also known as linear frequency transposition (Kuk *et al.*, 2006).
- **Frontal lobe:** Frontal refers to the anterior part of an organ or the body. The frontal lobe is the part of the brain before the central fissure and above the horizontal part of the lateral fissure (Brink, 1997:163).
- **Fundamental frequency:** The lowest component frequency of a periodic wave or quantity (Mueller & Hall, 1998:927).
- **Heschl's gyrus:** The areas of auditory reception are in the temporal lobes on both sides of the cerebral cortex in an area called Heschl's gyrus or also known as the superior temporal gyrus. It is the convolution of the temporal lobe believed to be the seat of language comprehension of the auditory system (Martin & Clark, 2000:365).
- **Insertion gain:** The difference in SPL produced by the hearing aid at a point in the ear canal and the SPL at the same point in the ear canal without the hearing aid. The difference between the two recordings (an un-instrumented equalization reference and an instrumented frequency response) is called the hearing aid insertion gain (Mueller & Hall, 1998:932).
- **Limbic system:** Complex system of brain nuclei and connections, including the hippocampus, amagdala, and fornicate gyrus, responsible for influencing endocrine and autonomic motor systems, affecting motivational and mood states (Stach, 2003:155).
- **Motor areas:** The part of the cerebral cortex that is involved with the central regulation of voluntary movement (Brink: 1997:312).

- **Musical scale:** A series of notes (symbols, sensations, or stimuli) arranged from low to high by a specified scheme of intervals, suitable for musical purposes (Mueller & Hall, 1998:941).
- **Music perception:** Music is defined as sounds that are put together in a pattern and performed by people who are singing or playing instruments (Collins, 1989:514) while perception refers to the recognition of physical phenomena by using one's senses (Collins, 1989:581). Music perception therefore refers to the recognition of music by using the hearing sense.
- **Non-linear frequency compression**: In hearing aid terminology non-linear refers to a hearing aid with overall gain and/or frequency-response change as a function of changing input signals (Mueller & Hall, 1998:943), therefore amplification of which the gain is not the same for all input levels (Stach, 2003:187). Non-linear frequency compression hearing aids therefore make use of non-linear amplification but are also equipped with a frequency compression algorithm to compress and shift otherwise inaudibly high frequencies into an adjacent lower frequency area and by doing this extend the audible range of hearing.
- **Octave:** The interval between two sounds having a basic frequency ratio of two, or, the pitch interval between two tones which is of such a nature that one tone may be regarded as duplicating the basic musical import of the other tone at the nearest possible higher pitch. One octave is equal to 1200 musical cents (Mueller & Hall, 1998:944).
- **Peak input-limiting level:** This refers to the most intense sound that can enter a hearing aid, and is typically implemented as a limiter immediately after the microphone at the 'front-end' of the hearing aid (Chasin 2006:22).
- **Perceptual smearing:** For normal hearing individuals, spectral selectivity derives from the different frequency components of the acoustic stimulus being separated into different auditory filters, with each component resulting in activity at discrete sites along the basilar membrane (Looi, McDermott, McKay & Hickson, 2008b:431). For hearing aid users, the auditory filters are broadened due to cochlear hearing loss with the perceptual consequence that the frequency selectivity is reduced and therefore smearing of the different frequency components occur (MacDonald, Pichora-Fuller & Schneider, 2010:1).
- **Pitch:** The subjective impression of the highness or lowness of a sound. The psychological correlate of frequency (Martin & Clark, 2000:66).
- **Planum temporale:** Temporal surface/side (Brink, 1997:383).

- **Primary auditory cortex:** The auditory cortical region, located on the superior plane and insula of the superior gyrus of the temporal lobe, which initially receives information from lower parts of the brain, such as the thalamus and brain stem.
- **Probe microphone:** A tiny microphone, often attached to a soft, small tube, placed within the external ear canal to measure sound intensity level near the eardrum. The probe microphone is connected to equipment for recording characteristics of sound (Mueller & Hall, 1998:950).
- **Recruitment:** A term commonly used in referring to abnormally rapid growth in loudness. A large increase in the perceived loudness of a signal produced by relatively small increases in intensity above threshold, symptomatic of some hearing losses produced by damage to the inner ear (Mueller & Hall, 1998:953).
- **Rhythm:** A regular movement or beat or a regular pattern of changes (Collins, 1989:683).
- **Severe hearing loss**: Mueller & Hall (1998:929) define a hearing loss as a problem with hearing that is characterized by decreased sensitivity to sound in comparison to normal hearing. A severe hearing loss refers to a loss of hearing sensitivity of 60 dB HL to 90 dB HL (Stach, 2003:240).
- **Sloping (configuration):** A term used in describing the configuration of a pure-tone audiogram, that is, how hearing loss varies as a function of test frequency. A sloping configuration shows progressively greater hearing loss for higher test frequencies (Mueller & Hall, 1998:959).
- **Speech perception:** Speech processing through sound detection, speech sound discrimination, word recognition and comprehension (Thibodeau, 2000:282).
- **Threshold knee-point (TK):** Also known as compression threshold. Knee-point in hearing aids refers to the intensity level at which compression is activated (Stach, 2003:147).
- **Timbre:** Characteristic feature of a sound or pitch (Brink, 1997:486). Attribute of auditory sensation in which a subject can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar (Mueller & Hall, 1998: 965).
- **Tonal music:** Music composed of musical elements (e.g. tones and chords), which are arranged in a specific order. The selection and ordering of these elements result in the induction of a key, where music elements are associated with certain tonal functions. Tonal

functions are evoked by a sequence through its implied or accompanying harmony and are associated with varying levels of perceptual stability (Van Egmond & Boswijk, 2007:31).

- **Vent:** An opening (e.g. 1 mm or 2 mm diameter) coursing from the lateral face to the medial tip of an ear mould or hearing aid; used for pressure equalization and sound transmission.
- **Wide dynamic range compression (WDRC):** Hearing aid compression that is activated throughout most of the dynamic range, typically resulting in greatest gain for soft sounds and least gain for loud sounds (Stach, 2003:64)

1.5 ABBREVIATIONS

The text of this study contains discipline specific abbreviations. The following list of abbreviations and their meanings is provided:

Abbreviation/Acronyms	Full form
AMICI	Appreciation of Music in Cochlear Implantees Test
ANOVA	Analysis of variance
ASHA	American Speech Language and Hearing Association
dB	Decibel
dB HL	Decibel hearing level
dB SPL	Decibel sound pressure level
BTE	Behind-the-ear
CAMP	Clinical Assessment of Music Perception Test
CAT	Computerized-Adaptive Tests
CI	Cochlear implant/implantees
cm^3	cubic centimetre
daPa	deka Pascal
DPOAE	Distortion product oto-acoustic emission
DSL	Desired Sensation Level Method
dSC	Digital Super Compression

dWDRC	Digital Wide dynamic range compression
EBP	Evidence-based practice
HPCSA	Health Professions Council of South Africa
Hz	Hertz
kHz	Kilo Hertz
km/h	Kilometre per hour
MBEA	Montreal Battery for Evaluation of Amusia
MERT	Musical Excerpt Recognition Test
MPO	Maximum Power Output
MPT	Music Perception Test
ms	Millisecond
NAL	National Acoustics Laboratories Method
NDoH	National Department of Health
NFC	Non-linear frequency compression
OAE	Oto-acoustic emission
Par.	Paragraph
PMMA	Primary Measures of Music Audiation Test
PTA	Pure tone average
PTC	Psychophysical Tuning Curves
REM	Real-ear measurements
REAR	Real-ear aided response
REUR	Real-ear unaided response
SABS	South African Bureau of Standards
SAMA	South African Music Awards
SAT	Self-Adapted tests
SPL	Sound pressure level
TEN test	Threshold Equalizing Noise Test
TK	Threshold Knee-point
UP	Ultra Power
WDRC	Wide Dynamic Range Compression
WHO	World Health Organization

1.6 OVERVIEW OF CHAPTERS

This section entails a brief description of the chapters included in the current study.

- **Chapter 1: Orientation and problem statement**

This chapter provides an overview of the importance of knowledge regarding hearing loss as the initial step to appropriate service delivery. The high prevalence of hearing disorders as well as difficulties associated with a hearing loss is highlighted. Lastly, cochlear dead regions as well as hearing aid processing of speech and music stimuli are discussed. Through the above, the aim of the study, namely to determine the influence of non-linear frequency compression on music perception, is emphasized. The chapter concludes with definitions of terms as well as clarification of abbreviations and acronyms used throughout the study.

- **Chapter 2: Music perception**

The importance of suitable adjustments on hearing aids for musical stimuli is discussed and the researcher provides a summary of music perception. Furthermore, the researcher motivates the compilation of the music perception test that was designed for use in this study and presents an overview of the said test.

- **Chapter 3: Non-linear frequency compression in hearing aids**

In Chapter 3 detailed information regarding frequency lowering and specifically non-linear frequency compression is provided and placed within the context of evidence-based principles. Through this information the importance of appropriate hearing aid fittings as strategy for the improvement of the quality of life of persons with a hearing loss are emphasized.

- **Chapter 4: Method**

This chapter describes the operational framework that is implemented for the conduction of the empirical research. The framework dictates the scientific process that is implemented to determine the influence of non-linear frequency compression on music perception by stating the aims of the research and explaining the research design. Furthermore, selection of participants, as well as data collection and research procedures are described. A detailed account of the ethical considerations is also provided.

- **Chapter 5: Results**

In Chapter 5 the results that were processed by means of statistical analysis are presented.

- **Chapter 6: Discussion of results**

Results are discussed in accordance with the sub-aims presented in Chapter 4. After presentation of the results pertaining to each sub-aim its significance, meaning and implications are discussed with reference to the relevant literature.

- **Chapter 7: Conclusion and recommendations**

Chapter 7 presents a conclusion based on the findings and provides a framework of the value of the results and how they may contribute to current knowledge. The study is critically evaluated and recommendations for future research are made.

1.7 CONCLUSION

Satisfactory enjoyment of music depends primarily on the audibility of musical sounds for the person with a hearing loss. Conventional hearing aids are often unable to provide adults with a hearing loss with sufficient musical information in order to enjoy music. This may lead to numerous frustrations for music lovers. A modification of the output of hearing aids in the form of non-linear frequency compression may improve the music perception abilities of some adults with a hearing loss. Non-linear frequency compression technology attempts to provide the listeners with better audibility of high frequency musical sounds by lowering high frequency information to lower frequencies where more residual hearing is present. This will enable music lovers to hear musical sounds that were previously missed and therefore may contribute to their enjoyment of music. Therefore, this study aims at determining whether non-linear frequency compression affects the musical perception abilities of adults presenting with a moderate to severe hearing loss, and if so, in which way.

1.8 SUMMARY

In this chapter the researcher aimed to provide relevant background information to clarify the theme of this study and to provide a holistic perspective of the importance of the rationale. Information regarding hearing loss in general and specifically a high frequency hearing loss is provided. Further information includes cochlear dead regions and an introduction to frequency lowering hearing aids. Lastly, the chapter focuses on music perception, differences between music and speech and the challenges presented to an audiologist confronted with the fitting of hearing aids for music lovers. The information in this chapter highlights a distinct need for appropriate audiological service delivery to persons fitted with hearing aids who also enjoys music, thereby emphasizing the importance of this study.

Chapter 2

MUSIC PERCEPTION

Chapter aim: This chapter serves as a theoretical basis for the empirical research and provides a critical evaluation as well as interpretation of the relevant literature. The focus is placed on music perception tests described in the literature and the development of the music perception test used as data collection material in this study.

2.1 INTRODUCTION

With recent improvements in speech recognition through hearing aids and cochlear implants, other aspects of auditory performance, including the appreciation of music, are becoming increasingly important (Spitzer, Mancuso & Cheng, 2008:57). This escalation of interest in the accuracy of music perception and the enjoyment of music is also reflected in publications of a variety of investigative experimental studies that assessed performance on musical tasks. As advanced hearing aid technology is introduced clinically, its impact on musical performance has become an assessment area of interest.

There is no standard test of music perception, and to compound the problem, different musical styles thrive in strikingly different acoustical environments (Wessel *et al.*, 2007:1). A further limitation to the choice of currently available measures for the assessment of music skills is that most music tests are advanced and specifically designed to examine the skills of individuals undergoing formal music training (Don *et al.*, 1999:158). Previous studies on assessment of music perception in cochlear implant recipients (Gfeller, Olszewski, Rychener, Sena, Knutson, Witt & Macpherson, 2005; Gfeller, Witt, Adamek, Mehr, Rogers, Stordahl & Ringgenberg, 2002; Gfeller, Turner, Mehr, Woodworth, Fearn, Knutson, Witt & Stordahl, 2002; Gfeller, Witt, Woodworth, Mehr & Knutson, 2002; Gfeller, Woodworth, Robin, Witt & Knutson, 1997; Gfeller & Lansing, 1991) confirmed the difficulty of assessing the perception of music and highlighted the need for a clinically relevant/appropriate measure of music recognition and performance (Spitzer *et al.*, 2008:57).

2.2 THE PERCEPTION OF MUSIC

Music is a very complex and wide-ranging phenomenon (Leal, Shin, Laborde, Calmels, Verges, Lugardon, Andrieu, Deguine & Fraysse, 2003:826) and its definition differs among various cultures and social milieus. Cross (2006:80) suggests that music can be best explored in terms of a tripartite model that embraces music as *sound* (what might conventionally be thought of as constituting music from Western perspective), as *behaviour* (which embraces the musical and 'non-musical' acts of musicians (the activities in which the production of music is embedded), and as *concept* (how people think about music in terms of its powers and its relations to other domains of human life).

A basic observation of music psychology is that listening to music may give rise to a large variety of experiences that are based on highly interrelated emotional and cognitive processes in the brain (Kreutz, Schubert & Mitchell, 2008:57; Iakovides, Iliadou, Bizeli, Kaprinis, Fountoulakis & Kaprinis, 2004:2). For example, one individual's deepest appreciation of music may be based on the structural features of a musical work, whereas for another individual the emotional content of a piece of music may elicit strong experiences. Thus the possibility arises that music processing depends on cognitive styles that vary between individuals as well as numerous participative factors that influence enjoyment, including personal preferences for musical genres and the situational context such as the listening environment and the listener's mood (Kreutz *et al.*, 2008:57; Nimmons, Kang, Drennan, Longnion, Ruffin, Worman, Yueh & Rubinstein, 2008:149). The effect of temporal context in music – what was played before and what is about to be played – continuously influences a listener's experience. An identical physical stimulus may be perceived differently, depending on the context; therefore, music perception is a dynamic, time-dependent process. Changes in loudness of musical performance are but one example of temporal dynamics of music in the greater sense. Other examples include fluctuations in tempo, changes in pitch, and adjustments in timbre (Vines, Nuzzo & Levitin, 2005:137).

These participative factors mentioned above may all greatly affect music perception and thereby render it difficult to measure. Thus, many studies focus on the objective characteristics of sound, which can be described in terms of physical parameters of the acoustic signals (Nimmons *et al.*, 2008:149). Several structural features of music that have been examined with regard to music perception include pitch, melody, rhythm, timbre and intensity (Deutsch, 2007:4473; Iakovides *et al.*, 2004:4). Musical perception primarily involves pattern perception, be it variations in rhythm, pitch, loudness or timbre. Whereas the sequencing of patterns of pitch forms the musical correlates of melody and harmony, the sequencing of patterns of duration or tempo forms the foundation of rhythm. However, although these attributes are separate entities, the combinations of, and interactions between the different attributes largely contribute to music as we commonly know it (Looi, McDermott, McKay & Hickson, 2008a:258).

One of the fundamental components of music is **pitch**, which can be operationally defined as the attribute of sound that carries melodic information (McDermott & McKay, 1997:1622). Pitch perception is an important underlying component of music perception, as melody recognition strongly depends on perceiving exact pitch intervals between successive notes (Galvin, Fu & Nogaki, 2007:303; McDermott & McKay, 1997:1622), therefore variations in pitch are central to our experience of melody, harmony and key (Chasin & Russo, 2004:39). The discrimination of the pitch of complex sounds by persons with a hearing loss has been studied relatively little, despite the fact that it is of both practical and theoretical interest (Moore & Peters, 1992:2881). One example of practical interest stems from the relevance of pitch discrimination for speech perception. The pitch patterns of speech indicate the most important words in an utterance, in many languages they distinguish between a question and a statement and they indicate the structure of sentences in terms of phrases (Moore & Peters, 1992:2881). When the pitch of complex signals, particularly musical sounds, is perceived to change the underlying physical parameter that has changed is the fundamental frequency (McDermott, 2005:70). Changes in the fundamental frequency result in corresponding changes in the frequency of all the harmonics (multiples of the fundamental) contained in the spectrum. An increase in the fundamental frequency, perceived as a pitch increase, corresponds to an increase in the spacing between the harmonic components of the signal (McDermott, 2005:70).

In normal hearing, the pitch of a sound is thought to be extracted from the place of stimulation in the cochlea (place code), by resolving frequency components in the neural firing pattern (temporal code), or possibly by analyzing phase components across the signal spectrum at different cochlear locations (Galvin *et al.*, 2007:303).

A difficulty faced by researchers in assessing pitch is that relatively few people have sufficient knowledge of musical terminology, or sufficient experience in judging musical pitch relationships (McDermott & McKay, 1997:1622). One solution to this problem is to make use of portions of familiar melodies as exemplars of pitch intervals. However, this imposes several constraints on a researcher. Firstly, only a few different intervals occur in the most easily recognized tunes; secondly, it is difficult to isolate the perceived pitch or a specific interval from confounding effects such as the rhythm or the overall pitch contour of the melody; thirdly, it is difficult to identify enough suitable tunes with which most persons with a hearing loss are familiar. Moreover, it is reasonable to doubt the accuracy of a person's memory for pitch intervals, even in the context of well-known melodies, particularly if he or she has endured a long period of auditory deprivation before receiving amplification (McDermott & McKay, 1997:1622).

Melodic perception, which develops from infancy, relies on a sensitivity to change over time, as does the perception of harmonic chord progressions and rhythmic relations (Vines *et al.*, 2005:137). Familiar melody recognition is the most common task used to measure music perception in persons with cochlear implants (Cooper *et al.*, 2008:618). However, the use of familiar melody recognition tasks in music perception research also presents some challenges. Firstly, the reliance of these tasks on a person's memory presents a problem, particularly for persons with a severe hearing loss who were deaf for a long duration before being fitted with hearing aids or having received a cochlear implant, because it is difficult to ascertain the level of familiarity a person has had with a given melody. Secondly, a person's ability to recognize a familiar melody provides little information about the individual mechanisms that underlie the melody recognition process. Accordingly, when people with a hearing loss perform poorly on familiar melody recognition tasks, as is often the case, little is learned about why their level of performance is low. Thirdly, these tasks are of little to no use in measuring music perception by pre-lingually deaf persons because familiar melody recognition tasks rely on the memory of a familiar melody, memories that were never formed by congenitally deaf individuals (Cooper *et al.*, 2008:618).

Melody recognition depends greatly on cues provided by rhythm (Galvin *et al.*, 2007:313) but also requires a degree of accurate pitch perception (Looi *et al.*, 2008b:429). Although melodies are inherently rooted in time and have their own temporal structure and phrasing, it is the pitch relationship of one note to the next which is the signature of a particular melody

(Limb, 2006:441). Both the intervals between individual notes and the overall contour of the sequence are incorporated into the processing of melody. The proper perception of melodies (and chords of notes presented simultaneously) rests on the accurate processing and cognitive perception of individual pitches (Limb, 2006:442). Perceiving the pitch of a complex sound primarily involves the listener having to extract information about the fundamental frequency form the complex acoustic signal. A range of environmental, physiological, and pathological phenomena could affect an individual's ability to perceive pitch. Examples of these variables include their memory for melodic pitches, music knowledge and/or training, the amount of residual hearing, pathological processes and central processing factors (Looi *et al.*, 2008b:429). It may however be hypothesized that many common tunes can be recognized when only rhythm is perceived while any pitch cues are absent (McDermott, 2005:68).

The creation of rhythmic patterns is arguably the most basic of all musical impulses, common even to primitive societies and children (Limb, 2006:442). **Rhythm** is defined as the organization of relative durations of sound and silence (or notes and rests), and differs from meter, which is the division of rhythmic patterns according to equal periods (or measures marked by an underlying tempo) (Limb, 2006:442). Musical rhythmic behaviour can be viewed as a constellation of concurrently operating, hierarchically organized, sub-skills including general timing abilities, smooth and ballistic movement (periodic and non-periodic), the perception of pulse, a coupling of action and perception, and error correction mechanisms (Bispham, 2006:125). Of all components of music perception, rhythm is the most fundamentally linked to the movement of time and therefore perception of rhythmic patterns necessarily implicates brain regions involved in temporal processing.

Timbre is the subjective impression of sound that enables one to differentiate between sounds having the same pitch, loudness, and duration, such as when distinguishing the same musical note played on different instruments (Nimmons *et al.*, 2008:149). It includes the features of a sound that do not directly relate to pitch or loudness, and is usually assessed by instrument identification tasks (Looi *et al.*, 2008a:258). The physical variables that contribute to our experience of timbre include the spectrum, temporal envelope, and transient components of a tone (Chasin & Russo, 2004:39). Changes in timbre can often be described in terms such as "lower" or "higher" and therefore are sometimes confused with changes in pitch, especially by non-musicians (McDermott, 2005:70).

Music perception consists of various components that work together to give each individual a unique perception of music. These components are visually presented in Figure 2-1 below:

Music perception: The recognition of music by using your hearing sense.

Pitch:
The attribute of sound that carries melodic information. Pitch perception is an important component of music perception as melody recognition strongly depends on perceiving exact intervals between successive notes and variations in pitch are central to experience melody, harmony and key.

Melody:
A linear succession of musical tones/pitches which is perceived as a single entity and forms a musical phrase. Melodic perception relies on a sensitivity to change over time, as does the perception of harmonic chord progressions and rhythmic relations. Melody recognition depends on pitch perception and rhythm cues.

Rhythm:
The organization of relative durations of sound and silence (or notes and rests). Musical rhythmic behaviour can be viewed as a constellation of concurrently operating, hierarchically organized, sub-skills including general timing abilities, smooth and ballistic movement (periodic and non-periodic), the perception of pulse, a coupling of action and perception, and error correction mechanisms.

Timbre:
The subjective impression of sound that enables one to differentiate between sounds having the same pitch, loudness, and duration, such as when distinguishing the same musical note played on different instruments. It includes the features of a sound that do not directly relate to pitch or loudness, and is usually assessed by instrument identification tasks.

The musical input modules

Pitch content: Deals with the melodic contour and tonal functions of successive pitch intervals.

Temporal content: The "rhythm analysis" component deals with the segmentation of the ongoing sequence into temporal groups on the basis of durational values.
The "meter analysis" component extracts an underlying temporal regularity or beat, corresponding to periodic alternation between strong and weak beats.

Musical lexicon: A representational system that contains all the representations of the specific musical phrases to which one has been exposed during one's lifetime. The same system also keeps a record of any new incoming musical input. Accordingly, successful recognition of a familiar tune depends on a selection procedure that takes place here. The output of the musical lexicon can feed two different components, depending on task requirements. If the goal is to sing a song like *Happy Birthday*, the corresponding melody, represented in the musical lexicon will be paired with its associated lyrics that are stored in the phonological lexicon and will be tightly integrated and planned in a way that is suitable for vocal production. If the task requires retrieving non-musical information about a musical selection, such as naming the tune or retrieving a related experience from memory, the associated knowledge stored in the 'associative memories' component will be invoked.

Emotion expression analysis: In parallel with memory processes, but independently, the perceptual modules will feed their outputs into an emotion expression analysis component, allowing the listener to recognize and experience the emotion expressed by the music. This emotional pathway also contributes to recognition via the musical lexicon. Emotion expression analysis is a pivotal processing component because music has the power to elicit strong emotional response. It takes input emotion-specific musical features, such as mode (e.g. major or minor) and tempo (e.g. slow or fast) as computed by the melodic and temporal pathways, respectively.

Figure 2-1: Components of music perception

Considering the diagram above, music perception can be summarized as follows:

Central to pitch organization is the perception of pitch along musical scales (Peretz & Coltheart, 2003:689). A musical scale refers to the use of a small subset of pitches (usually seven) in a given musical piece. Scale tones are not equivalent and are organized around a central tone, called the tonic. Usually, a musical piece starts and ends on the tonic. The other scale tones are arranged in a hierarchy of importance or stability, with the fifth scale tone and the third scale tone being most closely related to the tonic. The remaining scale tones are less related to the tonic, and the non-scale tones are the least related; the latter often sounding like 'foreign' tones. This tonal hierarchical organization of pitch facilitates perception, memory and performance of music by creating expectancies (Peretz & Coltheart, 2003:689).

There is substantial empirical evidence that listeners use this tonal knowledge in music perception automatically (Peretz & Coltheart, 2003:689). Tonal organization of pitch applies to most types of music, but it does not occur in processing other sound patterns, such as speech. Although the commonly used scales differ somewhat from culture to culture, most musical scales use pitches and afford the building of pitch hierarchies (Peretz & Coltheart, 2003:689).

The musical input modules are organized in two parallel and largely independent sub-systems of which the functions are to specify, respectively, the **pitch content** (the melodic contour and the tonal functions of the successive pitch intervals) and the **temporal content**, by representing the metric organization as well as the rhythmic structure of the successive durations (Peretz & Coltheart, 2003:689). The 'rhythm analysis' component deals with the segmentation of the ongoing sequence into temporal groups on the basis of durational values without regard to periodicity, whilst the 'meter analysis' component extracts an underlying temporal regularity or beat, corresponding to periodic alternation between strong and weak beats. The strong beats generally correspond to the spontaneous tapping of the foot. Both the melodic and temporal pathways send their respective outputs to either the 'musical lexicon' or the 'emotion expression' analysis component (Peretz & Coltheart, 2003:690). The **musical lexicon** is a representational system that contains all the representations of the specific musical phrases to which one has been exposed during one’s lifetime. The same system also keeps a record of any new incoming musical input. Accordingly, successful recognition of a familiar tune depends on a selection procedure that takes place in the musical lexicon. The output of the musical lexicon can feed two different components, depending on task requirements. If the goal is to sing a song like *Happy Birthday*, the corresponding melody, represented in the musical lexicon, will be paired with its associated lyrics that are stored in the phonological lexicon and will be tightly integrated and planned in a way that is suitable for vocal production. If the task requires retrieving non-musical information about a musical selection, such as naming the tune or retrieving a related experience from memory, the associated knowledge stored in the 'associative memories' component will be invoked (Peretz & Coltheart, 2003:690).

In parallel with memory processes, but independently, the perceptual modules will feed their outputs into an 'emotion expression' analysis component, allowing the listener to recognize and experience the emotion expressed by the music (Peretz & Coltheart, 2003:690). This emotional pathway also contributes to recognition via the musical lexicon. **Emotion expression analysis** is a pivotal processing component because music has the power to elicit strong emotional response. It takes input emotion-specific musical features, such as mode (e.g. major or minor) and tempo (e.g. slow or fast) as computed by the melodic and temporal pathways respectively (Peretz & Coltheart, 2003:690).

Musical skills are not typically associated with a specific brain hemisphere and neuropsychological investigations of musical abilities are often contradictory, this is a likely consequence of the complex nature of music (Don *et al.*, 1999:155). Nevertheless, research based on listening tasks, infant development, and lesion analysis reveals clues to the neurobiology and neuro-anatomy of music processing and concluded that music is processed in both hemispheres of the brain within the primary and secondary auditory cortices (Don *et al.*, 1999:155; Kuk & Peeters, 2008: par. 7). While the right hemisphere is responsible for the processing of timbre, pitch, and melody, the left hemisphere process rhythmic information (Andrade & Bhattacharya, 2003:285; Tervaniemi & Hugdahl, 2003:241; Don *et al.*, 1999:155).

All sound processing begins with the peripheral auditory apparatus, in which sound vibrations are transmitted to the cochlear inner hair cells (via the ear canal, tympanic membrane, and ossicular chain) (Limb, 2006:436). The early process of acoustic deconstruction takes place within the cochlea, which responds to acoustic vibrations in a frequency dependent fashion and triggers afferent potentials that travel down the cochlear nerve to the brainstem. Through a chain of sub-cortical processing structures (cochlear nuclei, olivary pathways, lateral lemnisci, inferior colliculi, and medial geniculate nuclei of the thalamus), neural impulses representing sound information eventually reach the auditory cortical structures (Limb, 2006:436). As the musical signal enters the primary auditory cortex it relays sound to the appropriate processing centres for further analyses, including the planum temporale, perisylvian language centres, motor areas, the frontal lobe and so forth (Kuk & Peeters, 2008: par. 7). The end result of this process is that of auditory percept (Limb, 2006:436). The processing of timing features of music begins as early as the cochlear nucleus with the brainstem. Processing of music is conducted in the Heschl's gyrus of the auditory cortex and the limbic system (Kuk & Peeters, 2008: par. 6). All auditory processing, whether environmental, linguistic, or musical in nature, relies on the integrity of this ascending auditory pathway (Limb, 2006:437). It is important to take note that the auditory cortex shows plasticity[11] throughout life (Tremblay, 2006:10) and in the case of a hearing loss, this is beneficial as it allows adaptation to behaviorally important sound and adapts easily to changes induced by a hearing loss and subsequent application of hearing aids or cochlear implants (Eggermont 2008:819).

The preceding information underlines the complexity of musical perception assessment and it is clear that many dimensions, such as pitch, timbre, rhythmic perception, melody recognition, and listening satisfaction may be evaluated to formulate a better understanding of music perception (Spitzer *et al.*, 2008:57).

2.3 PHYSIOLOGICAL EFFECT OF MUSIC

Music plays a central role in all human cultures, and for humans the experience of music is an important contribution to quality of life (Luis, Castro, Bastarrica, Perez-Mora, Madero, De Sarria & Gavilan, 2007:686). Both people with a hearing loss and normal hearing persons are continuously exposed to musical sounds in daily life. The idea that music conveys emotions seems an intuitive one; one only has to think of the central role played by music in social functions ranging from celebration (e.g. weddings) to grieving (e.g. funerals). One could

[11] Refers to the brain's capacity to change as a function of experience, reorganizing throughout the lifespan according to the auditory input that is available to the individual

easily posit that the pervasive nature of music in the world is largely due to its ability to evoke emotion (Limb, 2006:439).

The limbic system is associated with emotions and is highly involved in music processing (Kuk & Peeters, 2008: par. 8). Parts of the limbic system that have shown activity to music stimulation include the amygdale, hypothalamus, prefrontal cortex, and the ventral tegmental area. It has been seen in animal studies that exposure to slow instrumental music alters the level of certain neuro-trophins in the hypothalamus. These changes in the concentration of neuro-trophins could also lead to a reduced stress response, which is regulated by the hypothalamus. Happy musical pieces have been associated with activation of specific portions of the limbic system including the ventral striatum (bilaterally) and left hemisphere structures like the dorsal striatum, para-hippocampal gyrus and the anterior cingulated cortex. Sad musical pieces activate the right medial temporal structures, including the hippocampus and amygdale (Kuk & Peeters, 2008: par. 10).

Changes in a person's mood and emotions while listening to music have been linked to physiological changes in heart rate and respiration rate (Kuk & Peeters, 2008: par. 11). This may be mediated by changes in the release of arousal hormones, including epinephrine (adrenaline) and cortisl from the adrenal glands. The musical characteristics that may be responsible for influencing changes in heart rate of listeners include changes in tempo and aesthetics, intensity, rhythm, and texture (having to do with the number of voices or instruments) of music. Specifically, researchers found that participants' heart rates and respiration rates decreased over time when listening to a soothing piece of music. Music selected for the purpose of relaxation shares some common characteristics. These include providing a tempo at or below resting heart rate (60 to 72 beats per minute), predictable dynamics (soft or moderately loud), few changes in tempo, volume or instrumentation, fluid melodic movement, pleasing harmonics, regular rhythm without sudden changes, and tonal qualities that include flute, strings or piano. Sounds of the voice, organ and acoustical wind instruments are also recommended. In addition it is suggested including a greater number of lower pitches to promote relaxation (Kuk & Peeters, 2008: par. 11). However, heart rates remained the same and respiration rates increased over time in response to an exciting piece of music. The features reported as disruptive to relaxation included depressing music, loud volume, and high-pitched instruments (Kuk & Peeters, 2008: par. 15).

Recently, the effect of music in quality of life has been explored. The benefits of music and music therapy in physiological, psychological, and social-emotional aspects of a patient's life have been stressed. Music therapy has been proved to be useful for post-operative pain, as well as for anxiety, mood, comfort, and relaxation. Moreover, a significant difference has been reported in quality of life of patients with a terminal illness receiving music therapy (Luis *et al.*, 2007:686).

2.4 MUSIC PERCEPTION TESTS DESCRIBED IN THE LITERATURE

Because of the importance of music, some tests of music perception have been developed. Almost all of these tests focus on music perception in persons with cochlear implants. Gfeller and colleagues (2005, 1997 & 1991) began by adapting the *Primary Measures of Music Audition* test and also developed *the Musical Excerpt Recognition* test. Many other groups have also assembled in-house tests to evaluate cochlear implant strategies and designs developed by their laboratories (Kong, Stickney & Zeng, 2005:1355). The instruments used in these studies were designed to address specific research questions regarding perception of different structural features of music. The methods used were often similar, but they were not intended to be standardized tests and it is therefore not possible to directly compare results across laboratories (Nimmons *et al.*, 2008:150). Furthermore, most of these tests were developed to examine the music perception skills of cochlear implantees and was therefore not applicable to the evaluation of persons using hearing aids. Other motivations for not using existing music perception tests included the facts that test constructs were not pertinent to this study; tests were too lengthy for the time available, they required formal musical knowledge such as notation or technical vocabulary and test items might have been too difficult for the test population (Gfeller & Lansing, 1992:26). A detailed description of the existing music perception tests follow in Table 2-1:

Table 2-1: Existing music perception tests described in the literature

Purpose	Tasks	Procedure	Reasons for exclusion from this study
Appreciation of Music in Cochlear Implantees (AMICI)			
The test was developed to assess the ability of persons with cochlear implants to interpret musical signals (Spitzer *et al.*, 2008:56).	**Discrimination of music vs. noise:** The participant had to indicate whether the stimulus was noise or music (Spitzer *et al.*, 2008:60). **Timbre identification:** The participant held a list of instruments (trumpet, piano, flute, drum, tuba, guitar, violin, female and male vocal) and had to identify the musical instrument playing (Spitzer *et al.*, 2008:60). **Identification of musical styles:** The participant was presented with a musical piece from different musical styles (classical, Latin, country and western, jazz and rock and roll) and had to identify the musical style represented by each stimulus (Spitzer *et al.*, 2008:60). **Melody recognition:** The participant had to identify musical pieces, either popular or classical excerpts. Acceptable responses included naming the song, its composer, context in which it was used, singing or humming the melody (Spitzer *et al.*, 2008:60).	The test was administered in sound field in a sound attenuating booth, with stimuli presented through external speakers at 65 dB HL. The participant held a set of written instructions for each test section (Spitzer *et al.*, 2008:59).	♬ Was developed to interpret musical signals in cochlear implantees and not hearing aid users (Spitzer *et al.*, 2008:56). ♬ It addresses melody identification (part of pitch identification) and timbre identification but does not address rhythm. ♬ The melody identification task includes melodies familiar to American countries and the American culture which are not all familiar in South Africa (Spitzer *et al.*, 2008:63).
Clinical Assessment of Music Perception (CAMP)			
To develop a test to quantify music perception by cochlear implant (CI) listeners in a clinically practical manner that could be standardized for administration at any cochlear implant centre (Nimmons *et al.*, 2008:149).	**Melody identification:** Assessed recognition of common melodies from a closed set (Nimmons *et al.*, 2008:149). The listener was permitted to listen to all the test melodies during the practice session, after which each melody was presented three times in random order for identification. **Pitch direction discrimination**: Used a two alternative forced-choice adaptive procedure to determine a threshold interval for discrimination of complex pitch direction change (Nimmons *et al.*, 2008:149). On each presentation, a tone at the reference frequency and a higher pitched tone determined by the adaptive interval size were played in random order. The users were asked to identify which note was higher in pitch. The frequencies were distributed within the octave surrounding middle C (262 Hz) (Nimmons *et al.*, 2008:151). **Timbre identification:** Assessed recognition of eight commonly recognisable musical instruments from a closed set (Nimmons *et al.*, 2008:149). The instruments were recorded playing an identical melodic sequence composed specifically for this test. Listeners were permitted to listen to all the instruments during the practice session. Each instrument was presented three times in random order for identification.	The test was presented on a computerized interface developed on *Matlab 7* and run on an *Apple Powerbook*. The graphical interface consisted of large buttons that the listeners navigated using a mouse. The test was administered in sound field in a sound attenuating booth, with stimuli presented through external speakers at 65 dB HL. Listeners were allowed to adjust their cochlear implant volume to the most comfortable level of loudness (Nimmons *et al.*, 2008:152).	♬ This is a computerized test (Nimmons *et al.*, 2008:149). Service delivery in South Africa is characterised by limited resources and facilities (Johnsen, 1998:217) and the need for extra equipment to conduct the test will reduce the usage of such a test in South Africa. ♬ Was developed to quantify music perception in persons with cochlear implants and not hearing aid users (Nimmons *et al.*, 2008:149). ♬ It addresses pitch and timbre identification but does not address rhythm (Nimmons *et al.*, 2008:150). ♬ The melody identification task includes melodies familiar to European and Asian countries that are not all relevant to the South African context (Nimmons *et al.*, 2008:152).

Purpose	Tasks	Procedure	Reasons for exclusion from this study
	Medel Medical Electronics Mu.S.I.C. Perception Test		
To develop a test battery to quantify musical perception in cochlear implant users and to use as measurement tool to determine the effectiveness of cochlear rehabilitation (Medel Medical Electronics, 2006:1).	**Melody:** Determines a participant's ability to detect melodic differences between two short phrases. After a pair of melodies were played the participant had to decide if they were the same or different (Medel Medical Electronics, 2006:21). **Pitch:** Determines the participant's pitch difference limen by using a staircase algorithm. Pairs of descending and ascending sounds are played and the participant must select whether the second note is higher or lower in pitch by clicking the appropriate button (Medel Medical Electronics, 2006:18). **Distinguish chords:** Participant must distinguish between pairs of two piano chords and indicate whether they are the same or different (Medel Medical Electronics, 2006:22). **Rhythm:** Determines the participant's ability to distinguish temporal rhythms. Participant will hear pairs of rhythms and must decide if they were the same or different (Medel Medical Electronics, 2006:20). **What instrument:** Participants must identify what instrument they heard playing. To avoid the need for the participant to know the name of the instrument, responses are given by clicking on a picture of the instrument (Medel Medical Electronics, 2006:23). **Number of instruments:** Determines how many different instruments participants can distinguish in a piece of music (Medel Medical Electronics, 2006:24). **Emotional:** The participant needs to position a short piece of music on a happy-to-sad scale. Responses are given by indicating the appropriate number from one to ten (Medel Medical Electronics, 2006:25). **Dissonance:** This test asks participants to grade a piano chord on a consonance/dissonance scale, where one is the harshest possible sound and ten is the most melodious, smoothest sound (Medel Medical Electronics, 2006:26).	The test is delivered on DVD and first needs installation to a computer (Medel Medical Electronics 2006:3). The test was administered through the computer on a level comfortable to the participant (Medel Medical Electronics, 2006:9). The participant responded to each test by pressing the appropriate buttons on the computer screen (Medel Medical Electronics, 2006:9).	♬ Was developed to assess music perception in cochlear implantees and not hearing aid users. ♬ This is a computerized test (Medel Medical Electronics, 2006:3). Service delivery in South Africa is characterised by limited resources and facilities (Johnsen, 1998:217) and the need for extra equipment to conduct the test might reduce the usage of such a test in South Africa.
	Musical Excerpt Recognition Test (MERT):		
This test was designed to evaluate recognition of 'real-world' musical excerpts by cochlear implant users (Gfeller *et al.*, 2005:241).	The excerpts in the test represented the frequency range of orchestral music and the grand piano and consisted of complex multi-dimensional combinations of melodies and harmonies, timbres, rhythmic patterns and sometimes sung lyrics (Gfeller *et al.*, 2005:241). The excerpt selection was limited to pop, country and classical genres, the musical styles most commonly heard by the target populations of post-lingually deafened cochlear implant recipients and normal hearing adults. This test includes fifty musical excerpts representing a primary musical theme. To promote greater reliance on perception of the musical features (as opposed to lyrics), excerpts that included the title of the selection in the lyrics were excluded. The first five excerpts were practice items, the remaining 45 items consisted of 36 target items (8 familiar and 4 obscure for each genre), and 9 familiar target items (three from each genre) repeated to obtain indices of participant reliability (Gfeller *et al.*, 2005:242).	The sound level was averaged at 70 dB SPL, however implant recipients were permitted to adjust their processor for maximum comfort and normal hearing adults could adjust the volume on the speakers (Gfeller *et al.*, 2005:243). Test administration began with instructions on the computer screen and the five practice items. The participant listening to the items had to indicate whether or not the item sounded familiar.	♬ Was developed to assess recognition of musical excerpts in cochlear implantees and not hearing aid users (Gfeller *et al.*, 2005:241). ♬ This is a lengthy test of open-set recognition and music appraisal, which can take many hours and require trained musical personnel to code the responses (Nimmons, *et al.*, 2008:150).

Purpose	Tasks	Procedure	Reasons for exclusion from this study
	Montreal Battery for Evaluation of Amusia (MBEA)		
The MBEA was used to measure six different aspects of music perception along a melodic and temporal dimension (Cooper *et al.*, 2008:619). This test does not rely on the memory of familiar melodies, it is a measure based on cognitive theories and neuro-psychological evidence (Cooper *et al.*, 2008:619).	**Contour:** This test measures the ability to detect changes in the contour of the melody. It alters the contour of a melody by changing one note of the melody in such a way that its pitch height, respective to its neighbouring notes, is reversed (Cooper *et al.*, 2008:620). **Interval:** This test measures the perception of pitch step size information. The contour of the original melody is preserved but the pitch distance between the changed note and its neighbouring notes are altered (Cooper *et al.*, 2008:620). **Scale:** It measures the perception of musical scale information or tonality. The altered notes in the scale test are in the same pitch range as the altered notes used in the rules of the contour and interval tests. In contrast to these two measures, the altered note in the scale test is not in the correct (same) key and therefore sounds out of tune (Cooper *et al.*, 2008:621). **Rhythm:** It measures the perception of temporal aspects of music. It uses the same melodies as the previous tests but it is the duration of two adjacent notes that are altered rather than the pitch of the notes (Cooper *et al.*, 2008:621). **Meter:** Participants are required to indicate whether the melodic patterns were in either duple or triple meter, using the terms 'march' or 'waltz' respectively (Cooper *et al.*, 2008:621). **Melodic memory:** It consisted of 15 melodies from the previous tests and 15 unheard melodies. Participants are required to indicate whether the melody was presented in the earlier tests (Cooper *et al.*, 2008:621).	With the exception of the Meter and Melodic memory sub-tests in each task, participants listened to two melodies and indicated whether they were the same or different. For the meter tests, participants indicated whether the melodies were either a march or a waltz. On the sub-test for incidental memory, participants indicated whether the melody was presented in an earlier test (yes/no). In all conditions, participants indicated their response to each trial by marking with 'x' on a provided answer sheet (Cooper *et al.*, 2008:620).	♬ It was specifically designed for the evaluation of Amusia (Cooper *et al.*, 2008:618). ♬ The test was only evaluated as a possible test for using with cochlear implantees and not for persons with hearing aids (Cooper *et al.*, 2008:625). ♬ The pitch test appears to be too difficult for cochlear implantees and therefore is limited in its use. No information on persons with hearing aids is available (Cooper *et al.*, 2008:625). ♬ The melodic stimuli consist of a relatively low frequency range and are therefore not relevant for this specific study where the focus is placed on high frequency stimuli. The fundamental frequencies of the stimuli range from 247 to 988 Hz (Cooper *et al.*, 2008:625). ♬ This test addresses two aspects of music perception, namely rhythm and pitch but does not address timbre (Cooper *et al.*, 2008:625). ♬ It is a lengthy test and takes more than an hour to complete (Cooper *et al.*, 2008:619).
	Music Test Battery		
A music test battery was designed for evaluation of music perception in persons with cochlear implants (Looi *et al.*, 2008b:423).	**Rhythm:** Stimuli for this test were derived from the PMMA rhythm sub-test. The verbal prompts used in the original recording were eliminated for this study because of previously identified difficulties (Looi *et al.*, 2008b:423). **Pitch:** This test comprised three sub-tests, each identical in format but using differing interval sizes. The first sub-test consisted of pairs of one octave (12 semitones) apart, the second sub-test presented half-octave (6 semitones) intervals, and the third sub-test quarter-octave (3 semi-tones) intervals. Recordings of the vowels /i/ and /a/ were obtained from trained singers with the two notes of the same vowel, and sung	As testing was conducted at two different sites, the signals were not presented to participants in the sound field to avoid the effects of variable loudspeaker frequency response and room acoustics. Sound-isolation booths were used for all of the	♬ The melody test includes melodies familiar to the Australian population (Looi *et al.*, 2008b:425) which may not be recognized by South African people. ♬ It is a very lengthy test (about 4 hours) and therefore participants have to complete it in two or three sessions (Looi *et al.*, 2008b:426).

	by the same singer at the designated interval size. For half of the presentations, the first note was higher than the second (descending), while the other half was ascending. Participants were required to select the higher note for each stimulus pair (Looi *et al.*, 2008b:424). **Instrument:** This test consisted of three sub-tests, each with the same procedure but different stimuli. The first sub-test consisted of single instrument sounds, the second of solo instruments with background accompaniment, and the third involved music ensembles. For each sub-test, participants were presented with a list of the instruments or ensembles. They were instructed to name the instrument or ensemble that they though were playing (Looi *et al.*, 2008b:425). **Melody:** The first 15 seconds of well-known melodies were recorded, preserving the original rhythms. After each melody had been presented, participants were asked to name the melody from a list of melody titles (Looi *et al.*, 2008b:425).	testing. All stimuli were presented from a computer, connected to an external sound box and presented via earphones. Participant's responses were entered directly into the computer. For all the tests, participants selected their preferred listening settings on their device, and presentation levels were individually verified to be of a comfortable loudness (Looi *et al.*, 2008b:425).	
Primary Measures of Music Audiation (PMMA)			
This test was developed by Gordon in 1979 and assesses discrimination of short tonal and rhythm patterns (Gfeller & Lansing, 1991:917). It was used in musical perception experiments by Gfeller *et al.*, 1997, Gfeller & Lansing (1992) and Gfeller & Lansing (1991).	**Melodic (tonal):** Each melodic pattern contains from two to five notes ranging in pitch. The items have identical temporal patterns, but those item pairs that are different vary on one or more notes in frequency (Gfeller & Lansing, 1991:917). Respondents are asked to indicate if the item pair is the same or different. **Rhythm:** All stimuli are presented at the same frequency and differences are in duration or intensity of notes. Respondents are again asked to indicate whether the item pair is the same or different (Gfeller & Lansing, 1991:917).	Each participant was tested individually in a small room. Participants were asked to complete a questionnaire. The tests were played over a portable cassette tape recorder in sound field at most comfortable level of loudness (range of 65-84 dBA SPL) (Gfeller & Lansing, 1992:25).	♬ This test is normed on young children (up to grade three) (Gfeller & Lansing, 1991:917). ♬ One difficulty with the recorded format of the PMMA was the verbal prompt prior to each item pair: Each rhythmic pair or tonal pair is preceded by the name of an object (e.g. apple or leaf) and prompts of 'first' and 'second'. For some listeners these auditory stimuli might be perceived as a part of the signal for the discrimination task. Rather, a visual prompt is recommended before each item pair begins (Gfeller & Lansing, 1992:27). ♬ This is a lengthy test of open-recognition and music appraisal (Nimmons, *et al.*, 2008:150). ♬ The test requires trained musical personnel to code the responses (Nimmons, *et al.*, 2008:150).

Note that all the tests mentioned above were developed or used for cochlear implant users and no test for music perception for hearing aid users is available at present.

Additionally to the music perception tests described above, some academics did research regarding different aspects of music perception. No formal test was used in the research and they used material for the purposes of their particular studies only. Such research studies included:

♬ *Temporal stability of music perception and appraisal scores in adult cochlear implant recipients (Gfeller, Jiang, Oleson, Driscoll & Knutson, 2010).*

This study included the analysis of six measures of music perception or appraisal collected twice, approximately one year apart. The measures were:

- familiar melody recognition, which involved open-set recognition of 12 familiar melodies without lyrics (synthesized piano tones),
- timbre recognition, which involved closed set recognition of eight different musical instruments (recordings of solo instrumentalists playing a standardized melody),
- recognition of excerpts of real-world instrumental music (no lyrics),
- recognition of excerpts of real-world music with lyrics,
- appraisal of excerpts of real-world instrumental music (no lyrics), and
- appraisal of excerpts of real-world music with lyrics. The recordings of the real-world music tests were comprised of excerpts representative of three musical styles including classical, pop and country (Gfeller *et al.*, 2010:30).

♬ *Effects of training on recognition of musical instruments presented through cochlear implant simulations (Driscoll, Oleson, Jiang & Gfeller, 2009).*

Sixty-six adults with normal hearing completed three training sessions per week, over a five-week time period, in which they listened to the cochlear implant simulations of eight different musical instruments. Results indicated that different types of training are differently effective with regard to improving recognition of musical instruments presented through a degraded signal, with direct instruction being the most effective (Driscoll *et al.*, 2009:71).

- *The ability of cochlear implantees to recognise melodies as a function of melody frequency range, harmonicity and number of electrodes (Singh, Kong & Zeng, 2009).*
  In this study, 12 well-known melodies were used in low, mid and high frequency ranges to identify from a closed-set. The melodies were presented via direct connection from the speech processor of the cochlear implant to the computer with the volume adjusted to a comfortable level as judged by each participant. Each melody was played three times in random order, producing a block of 36 melodies (Singh *et al.*, 2009:162).

- *Multivariate predictors of music perception and appraisal by adult cochlear implant users (Gfeller, Oleson, Knutson, Breheny, Driscoll & Olszewski, 2008).*
  Cochlear implant recipients participated in a pitch ranking task, melody recognition task, the Musical Excerpt Recognition Test (MERT), timbre recognition, an excerpt appraisal task and several cognitive and speech measures to determine whether performance by cochlear implant users could be predicted from technological, demographic and life experience variables, as well as speech recognition scores (Gfeller *et al.*, 2008:124).

- *Melodic contour identification by cochlear implant listeners (Galvin et al., 2007).*
  Cochlear implantees were asked to identify one of nine five-note melodic contours. The interval between successive notes in each contour was systematically varied to test musical pitch resolution provided by the cochlear implant device (Galvin *et al.*, 2007:304). The 'root note' (i.e. the lowest note in the contour) was also varied to test whether there was optimal sensitivity to musical pitch in different frequency ranges. Three-harmonic complexes were used to represent the musical notes to test cochlear implant user performance in a multi-channel context. For comparison purposes, familiar melody recognition was also evaluated with two sets of 12 familiar melodies, in which the rhythm cues were either preserved or removed (Galvin *et al.*, 2007:304). Cochlear implant users were tested in free field in a sound-treated booth and stimuli were delivered via a single loudspeaker (Galvin *et al.*, 2007:306).

- *Temporal information processing in musicians and non-musicians (Rammsayer & Altenmuller, 2006).*
  This study included the following tasks:

Temporal discrimination task: Filled intervals were white noise bursts presented binaurally through headphones and empty intervals were marked by onset and offset clicks 3 ms in duration (Rammsayer & Altenmuller, 2006:39). Because interval timing may be influenced by the type of interval (filled vs. empty) and base duration, this task consisted of one block of filled and one block of empty intervals with a base duration of 50 ms each, as well as one block of filled intervals with a base duration of 1000 ms. The order of blocks was counterbalanced across participants. Each block consisted of 64 trials, and each trial consisted of one standard interval and one comparison interval. The duration of the comparison interval varied according to an adaptive rule to estimate x.25 and x.75 of the individual psychometric function, that is, the two comparison intervals at which the response 'longer' was given with a probability of .25 and .75, respectively. In each experimental block, one series of 32 trials converging to x.75 and one series of 32 trials converging to x.25 were presented. Within each series, the order of presentation for the standard interval and the comparison interval was randomized and balanced, with each interval being presented first in 50% of the trials. The participant's task was to decide which of the two intervals was longer and to indicate his decision by pressing one of two designated response keys. After each response, visual feedback was displayed on the computer screen (Rammsayer & Altenmuller, 2006:39).

Temporal generalization task: The stimuli were sine wave tones presented through headphones. The standard duration of the long intervals was 1000 ms and the non-standard durations were 700, 800, 900, 1100, 1200 and 1300 ms (Rammsayer & Altenmuller, 2006:39). The standard duration of the short intervals was 75 ms and the non-standard durations were 42, 53, 64, 86, 97 and 108 ms. Performance on temporal generalization was assessed separately for intervals in the range of milliseconds and seconds. Participants were required to identify the standard stimulus among the six non-standard stimuli. In the first part of the experiment, participants were instructed to memorize the standard stimulus duration. For this purpose, the standard interval was presented five times accompanied by the display 'standard duration' (Rammsayer & Altenmuller, 2006:39). Then participants were asked to start the test. The test consisted of eight blocks. Within each block, the standard duration was presented twice, while each of the six non-standard intervals was presented once. On each test trial, one duration stimulus was presented. Participants were instructed to decide whether or not the presented stimulus was of the same duration as the standard stimulus stored in the memory (Rammsayer & Altenmuller, 2006:40).

Rhythm perception task: The stimuli consisted of 3 ms clicks presented binaurally through headphones (Rammsayer & Altenmuller, 2006:40). Participants were presented with auditory rhythmic patterns, each consisting of a sequence of six 3ms clicks marking five beat-to-beat intervals. Four of these intervals were of a constant duration of 150 ms, while one interval was variable (150 ms + x). The value of x changed from trial to trial depending on the participant's previous response according to the weighted up-down procedure. Correct responding resulted in a decrease of x and incorrect responses made the task easier by increasing the value of x. The participant's task was to decide whether the presented rhythmic pattern was perceived as regular (all beat-to-beat intervals appeared to be the same in duration) or irregular (one beat-to-beat interval was perceived as deviant) (Rammsayer & Altenmuller, 2006:40).

Auditory flutter fusion task: The stimuli consisted of 25 ms noise bursts presented binaurally through headphones (Rammsayer & Altenmuller, 2006:40). Auditory flutter fusion threshold estimation consisted of 12 trials, and each trial consisted of two noise bursts separated by a variable period of silence ranging from 1 to 40 ms. After each trial, the participant's task was to indicate by pressing one of two designated keys whether he/she perceived the two successive noise bursts as one sound or two separate sounds. To enhance reliability of measurement, two auditory flutter fusion threshold estimates were obtained for each participant (Rammsayer & Altenmuller, 2006:40).

- *Speech and melody recognition in binaurally combined acoustic and electric hearing (Kong et al., 2005).*

  For the melody recognition experiment, three sets of 12 familiar melodies, consisting of single notes, were generated using a software synthesizer. For each melody, rhythmic information was removed by using notes of the same duration. Therefore, pitch was the only available cue for melody recognition (Kong *et al.*, 2005:1356) Three sets of the 12 melodies were generated in low-, mid-, and high frequency ranges. All participants were tested with cochlear implant, hearing aid and both in three melody conditions (low, mid and high) for a total of nine conditions. For either the hearing aid or the cochlear implant stimuli were presented at the participant's most comfortable level with the hearing aid or cochlear implant at its usual settings. The titles of the 12 melodies were displayed on a computer screen and the participant was asked to choose the melody that was presented. A practice session with feedback was given before the actual test. Repetition of the stimulus was not allowed and visual feedback regarding the correct response was given immediately after the participant's response (Kong *et al.*, 2005:1356).

♬ *Music perception with temporal cues in acoustic and electric hearing (Kong, Cruz, Auckland & Zeng, 2004).*

This study included tasks of tempo discrimination, rhythmic pattern identification and melody identification which are discussed below:

Tempo discrimination: Musical tempos were generated with a drum machine and it was measured with four standard tempos at 60, 80, 100 and 120 beats per minute. For each standard tempo, 21 or more tempos were used to pair with the standard tempo. Participants listened to these tempo pairs and were asked to identify the faster tempo in a two-interval, forced choice paradigm (Kong *et al.*, 2004:176).

Rhythmic pattern identification: All musical patterns were played on and recorded by a drum machine. It was measured at four standard tempos: 60, 90, 120 and 150 beats per minute. Each participant listened to two bars of drumbeats. The first bar was always a standard rhythmic pattern. The second bar contained one of the seven patterns displayed in a graphical representation. Participants were asked to choose the musical notation corresponding to the rhythmic pattern they heard. All participants were trained to read basic musical notation before the study (Kong *et al.*, 2004:177).

Melody identification: Two sets of 12 familiar songs, rendered in single notes, were generated using a software synthesizer. One set contained both rhythmic and melodic information (rhythm condition), whereas the other set contained only melodic information (no rhythm condition). In the no-rhythm condition, all melodies were played using notes of the same duration; therefore, pitch was the only available cue for melody recognition (Kong *et al.*, 2004:178). Both normal hearing and cochlear implant users were first tested with the original, unprocessed stimuli. In addition, normal hearing listeners were tested with all the rhythmic and no-rhythm processed stimuli (simulation). Cochlear implantees however, were only tested using 1-band with rhythm processed stimuli. The condition of

1-band without rhythm was not performed in the cochlear implantees because their performance was already near the chance level when presented with the original stimuli. The titles of the 12 melodies were displayed on a computer screen and the participants were asked to identify the melody from a closed set. All melodies were presented three times in random order for each experimental condition (Kong *et al*., 2004:178).

♬ *Music perception in adult cochlear implant recipients (Leal et al., 2003).*
The following sub-tests were included in this study:

Timbre: In order to obtain evaluative responses of perceptions of various timbres, the participants listened to short solo melodies produced by three commonly heard musical instruments representing different instrumental families and frequency ranges. These included wind (trombone), percussion (piano) and string families (violin). The participants were asked to identify each instrument. To reduce the structural variability of the phrases between instruments, all instruments were played using the same pitch scale. The instrumental recordings played the same French nursery melody (single note) (Leal *et al*., 2003:827).

Pitch: Twelve pairs of items with identical temporal patterns but differences in frequency were used. The pairs of items were sometimes similar and pitch was changed in an increasingly difficult manner. In the pitch discrimination test the respondents were asked to indicate whether the pair of items was the same or different and in the pitch identification test they were asked whether the pitch became higher or lower and where this change occurred (beginning, middle or end) (Leal *et al*., 2003:827).

Rhythm: This test was similar to the pitch test. They evaluated changes in duration or intensity of the notes by presenting ten pairs of musical pieces separated by five seconds of silence. All stimuli were presented at the same frequency. In the first part of the test (discrimination), respondents were asked to discriminate whether the pair of items was the same or different. In the second part (identification) they were asked to determine the point of change (Leal *et al*., 2003:827).

Song recognition: For this task, they showed participants a list of 16 songs and asked which ones they were familiar with. Eight songs were selected that the participant was familiar with and these songs (closed set) were presented at random. The songs were presented first by an orchestra without verbal cues, then played on piano (single note) and finally by an orchestra with verbal cues. Participants were asked to identify the songs by name or by singing a part of the song (Leal *et al.*, 2003:827).

- *Effects of frequency, instrumental family and cochlear implant type on timbre recognition and appraisal (Gfeller et al., 2002).*
  These researchers used timbre stimuli from eight different commonly known musical instruments (Gfeller *et al.*, 2002:350). These timbre stimuli were used in three different tasks, including timbre recognition (identification of the instrument being played by sound alone) and timbre appraisal which included the overall pleasantness of the sound and qualitative ratings for different timbre dimensions (Gfeller *et al.*, 2002:351). For the timbre recognition test, stimuli based on each instrument were presented three times in random order. After each melody was played the individual selected the instrument that he/she believed produced the sound just heard. In the general appraisal test participants were asked to appraise the overall pleasantness of items by touching a point along a 100 mm visual analogue scale (0 represents dislike very much and 100 represents like very much). Lastly participants were asked to rate the sound quality (Gfeller *et al.*, 2002:351).

- *Effects of training on timbre recognition and appraisal by post-lingually deafened cochlear implant recipients (Gfeller et al., 2002).*
  This study used the same timbre stimuli and procedures as in the previous study described by Gfeller *et al.* (2002), but with only evaluating participants before and after a training period.

- *Recognition of familiar melodies by adult cochlear implant recipients and normal hearing adults (Gfeller et al., 2002).*
  To conduct this study, the researchers included a familiar melody recognition task as well as a complex-tone discrimination task. Both of these are discussed below.

  Familiar melody recognition task: To identify items likely to be familiar to non-musicians, collections of songs commonly known to the general public in the United States were reviewed and a pool of song titles was submitted to a panel of university experts in music education, who verified that these were well-known melodies (Gfeller, *et* *al.*, 2002:34). Adult volunteers were tested individually in open-set recognition of 35 selected songs, played on piano and recorded on cassette tape (Gfeller, *et al.*, 2002:35). From the most familiar items, a subset of 12 was chosen. As prior research indicates that normal hearing adults and adults with cochlear implants rely on rhythmic features for melodic recognition, melodies were selected that could be grouped into two categories based on rhythmic features: items with distinctive rhythmic features within the melody line (e.g. dotted eight notes, triplet figures, etc.) and items made of quarter notes (no distinctive rhythm) with a half note at the closure of the musical phrase Gfeller, *et al.*, 2002:35). In addition to the 12 familiar melody items, the test included 12 foils, one for each of the familiar melodies. These newly composed items were created by using the durational values and the pitches of the familiar melodies, but in a new sequential order. Each familiar melody and its foil were presented in melody only, and melody plus harmony (no lyrics). All melody lines were presented in the same fundamental frequency range; melody-only versions included a fundamental frequency range of 194-659 Hz. Harmony versions consisted of the melody (figure) against background harmony (ground) (Gfeller, *et al.*, 2002:35). The harmony versions included a fundamental frequency range of 87 to 659 Hz. The melodies were presented in C major, and at the same tempo (Gfeller, *et al.*, 2002:36). The test was delivered via a computer with touch screen and external speakers in free field. The stimuli were transmitted through the speech processor and the sound level was set at 70 dB. First, the participant read standardized instructions for the test on the computer screen and practiced on two sample items. A total of 45 items (familiar and foils) were then presented in random order. Each familiar item was presented twice: melody-only and melody-plus-harmony format. Six item foils were presented in melody-only format and six in harmony format. A sub-group of nine items was repeated a second time during the test to determine internal consistency of participant responses (Gfeller, *et al.*, 2002:36).

Complex-tone discrimination task: The tone stimulus was a standard synthesized acoustic grand piano. A range of 36 semitones (three octaves) was used which has fundamental frequencies ranging from E (73 Hz) to C (553 Hz) (Gfeller, *et al.*, 2002:38). The task was a two alternate forced choice interval test. Two tones separated by silence were presented to the participant, who had to make a decision on whether the second tone was higher or lower in pitch than the first tone (Gfeller, *et al.*, 2002:38). The direction of the interval was also randomized for each presentation. This method was used to gather an overall and relatively quick assessment of discrimination across a wide frequency range. The used algorithm, which has a memory of the last three interval levels the user has achieved, adapts to the participant's response. Generally, if a participant responds correctly to the item, the interval size is reduced, based on previous interval levels tested. Likewise, when the participant responds incorrectly, the interval size is increased. The algorithm continues until it finds an interval size judged significantly correct. The minimum resolution of the test is one semitone, which is the smallest interval size on standard pianos and in the scale for traditional western music (Gfeller, *et al.*, 2002:39).

- *The ability of Nucleus Cochlear implantees to recognize music (Fujita & Ito, 1999).* These researchers tested the ability of persons with cochlear implants to recognize music (Fujita & Ito, 1999:634). They used 20 well-known nursery songs that were obtained from commercial cassette audiotapes and presented the stimuli at 65 to 75 dB SPL to the participants. Each participant was asked to recognize nursery songs (both open and closed set), distinguish among nursery songs with the same rhythm and pitch range, distinguish musical intervals played on the keyboard and distinguish which musical instrument (piano, banjo, violin, harp or trumpet) was being played on the keyboard. These tasks required about 1.5 hours to complete (Fujita & Ito, 1999:635).

- *Perception of rhythmic and sequential pitch patterns by normally hearing adults and adult cochlear implant users (Gfeller et al., 1997).*
  For this study the tonal and rhythmic sub-tests of the PMMA were used (Gfeller *et al.*, 1997: par. 19). The researchers also conducted a 6-pulse task. Stimuli for this rhythmic pattern task were computer generated square waves presented at 71 dB SPL. The frequency of each pulse was 440 Hz, and the duration of all pulses was equal. A given pattern consisted of six pulses separated by either of two inter-pulse intervals. Four of the inter-pulse intervals were equal in duration and called the long inter-pulse intervals. One of the intervals was 10% of the long inter-pulse interval and termed the short inter-pulse interval. Four different patterns were used, each differentiated by the position of the short inter-pulse interval (i.e. interval 1, 2, 3 or 4) (Gfeller *et al.*, 1997: par. 19). Participants were asked to listen and determine where in the entire pattern the short inter-pulse interval was perceived, either more toward the beginning or more toward the end of the pattern. To register their response, they were given a key pad with two buttons and instructed to push the button marked 'B' (for beginning) to indicate that the two closest pulses occurred

toward the beginning of the pattern or marked 'E' (end) to indicate the two closest pulses occurred toward the end of the pattern (Gfeller *et al.*, 1997: par. 20). Each participant was instructed through visual cues on the computer screen to listen to each stimulus item. Responses were automatically recorded by a computer for later data analysis (Gfeller *et al.*, 1997: par. 24).

♬ *Psychometric features and motivational benefits of Computerized-Adaptive and Self-Adapted Music-Listening tests (Vispoel & Coffman, 1994).*

A study was done with computerized-adaptive tests (CAT) and self-adapted tests (SAT) to demonstrate the features and benefits of both. Both tests measured tonal memory (the ability to remember tonal sequence) (Vispoel & Coffman, 1994:29). Two forms of the CAT and two forms of the SAT were constructed from non-overlapping item pools. One CAT form and one SAT form used Pool A whereas the other CAT and SAT form used Pool B. Items were selected for the pools in such a way that their information curves were essentially identical. Each test consisted of a series of short melodies played twice. Examinees indicated whether the melodies were the same or different; if different, they indicated the number of the single altered tone (Vispoel & Coffman, 1994:30). Each CAT and SAT was administered on a computer and terminated at 30 items. The CAT began with an item of medium difficulty. Examinees chose items from six difficulty levels when taking the SAT. If examinees responded to all items at a given level, they were asked to choose another level (Vispoel & Coffman, 1994:30).

♬ *Pitch discrimination and phase sensitivity in young and elderly participants and its relationship to frequency selectivity (Moore & Peters, 1992).*

All stimuli were digitally generated (Moore & Peters, 1992:2884). The complex tones were harmonic complexes composed of equal-amplitude harmonics with fundamental frequencies of 50, 100, 200 and 400 Hz (the range of voice pitch). The tones contained harmonics 1-12, 6-12, 4-12 and 1-5. For fundamental frequency of 400 Hz, the highest harmonic number was ten to insure that all harmonics were audible for all participants; absolute thresholds were typically increasingly elevated above 4 kHz for most of the participants with a hearing loss. The components of the harmonic complexes were added in one of two phase relationships, all cosine phase or alternating cosine and sine phase (Moore & Peters, 1992:2884). Frequency discrimination of pure tones was measured for frequencies of 50, 100, 200, 400, 800, 1000, 1200, 2000, and 4000 Hz. The level of the tones was 25 dB above the absolute threshold at the test frequency. Measurements were done using an adaptive three-interval, three-alternative forced-choice method. Each trial consisted of three observation intervals, marked by lights. In two of the intervals, the frequency of the stimulus was the same, while in the third, selected at random, the frequency was higher. The task of the participant was to select the observation interval containing the higher frequency. At least three threshold estimates were obtained for each condition (Moore & Peters, 1992:2884). Participants were given a small amount of training before data collection began. However, the three-interval task used in this study appears to be easier to learn than the two-interval task more commonly used and there was no evidence of participants improving during the course of the experiment. It seems likely that participants find it easier to pick the 'odd one out' than to decide whether a pitch ascended or descended (Moore & Peters, 1992:2885).

♬ *Melodic, rhythmic and timbral perceptions of adult cochlear implant users. (Gfeller & Lansing, 1991).*

  In order to obtain evaluative reports of perceived quality for varied timbres, participants listened to short taped excerpts of solo melodies produced on nine acoustic instruments (Gfeller & Lansing, 1991:918). These instruments were selected to represent a variety of harmonic spectra and frequency ranges. The instrumental recordings included familiar folk and semi-classical melodies. Following each example, participants completed a musical instrument quality rating form where they selected descriptors from lists of bipolar adjectives, such as beautiful/ugly. The participants were also asked to identify the melody and name the musical instrument (Gfeller & Lansing, 1991:918).

As mentioned before, all of the above were developed to assess cochlear implantees' performances on different aspects of music perception. These tests however, contain important aspects that need to be included in the development of a music perception test for hearing aid users.

2.5 DEVELOPMENT OF A MUSIC PERCEPTION TEST FOR HEARING AID USERS

It is important to consider the very complex and wide-ranging nature of music and to realize that the tasks in several studies regarding music perception in cochlear implant users represent a specific and narrow aspect of music listening. Music generally constitutes a unified whole that cannot be naturally subdivided (e.g. it is difficult to listen to the notes of a melody while ignoring its rhythmic underpinning and vice versa) (Limb, 2006:436). As such, it is plausible that the division of music into smaller musical elements may not be the best method to approach the subject of music at large. When participants hear all the musical parameters together their perception is not as good as when they hear them separately (Leal *et al.*, 2003:834). Fujita and Ito (1999) found the same outcome – good ability to recognize songs that were sung with instrumental accompaniment but poor ability to recognize songs played on a keyboard without verbal cues, indicating that patients recognized songs by verbal cues rather than by musical qualities such as tones and melodic intervals. Yet, in order to establish basic concepts, this approach has been commonly taken and has even been used to outline a modular organization for music processing. The scientific study of music perception has used stimuli based on both discrete musical elements and intact, musically rich stimuli (Limb, 2006:436).

As none of the tests mentioned above were designed for hearing aid users, none of them were used in this study. Therefore the researcher has decided to compile a music perception instrument for this study to serve the purpose of data collection. Depending on the results of this study, the self-compiled music perception instrument might possibly be accessible in South Africa for future use by students, audiologists in the hearing instrument dispensing market and audiologists involved with persons with cochlear implants.

Rhythm, timbre, pitch and melody are structural features of music that have been previously examined with regard to music perception and are important aspects to assess in order to gain insight into a person’s perception of musical stimuli (Deutsch, 2007:4473; Iakovides *et al.*, 2004:4). These aspects are discussed below because they form an integral part of any music perception test and because they are also included in the music perception test compiled for this study.

♬ **Rhythm**

Rhythm is described as a regular movement or beat or a regular pattern of changes (Collins, 1989:683). The major focus of rhythm perception is on discriminating a series of temporal patterns (Rammsayer & Altenmuller, 2006:38). Commonly, in a rhythm perception task, a participant is presented with a click pattern, devoid of any pitch, timbre, or dynamic variations to avoid possible confounding influences on perceived rhythm. In the self-compiled music perception test rhythm identification, discrimination, recognition and rhythm perception tasks were included.

♬ Timbre

Timbre is defined as the characteristic feature of a sound or pitch (Brink, 1997:486). It is an attribute of auditory sensation in which a participant can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar (Mueller & Hall, 1998: 965). This test evaluated timbre identification with single instruments and a combination of instruments playing together.

♬ Pitch

The participative impression of the highness or lowness of a sound is called the pitch and it is known to be the psychological correlate of frequency (Martin & Clark, 2000:66). Pitch perception is an important underlying component of music perception, as melody recognition strongly depends on perceiving exact intervals between successive notes (Galvin *et al.*, 2007:303). In normal hearing, the pitch of a sound is thought to be extracted from the place of stimulation in the cochlea, by resolving frequency components in the neural firing pattern, or possibly by analyzing phase components across the signal spectrum at different cochlear locations (Galvin *et al.*, 2007:303). Pitch sub-tests in this test included a pitch identification and pitch discrimination task.

♬ Melody

A melody, also tune, voice or line, is a linear succession of musical tones/pitches which is perceived as a single entity and forms a musical phrase (Limb, 2006:441). In its most literal sense, a melody is a sequence of pitches and durations, while, more figuratively, the term has occasionally been extended to include successions of other musical elements such as tone colour. Melodies often consist of one or more musical phrases and are usually repeated throughout a song in various forms. Melodies may also be described by their melodic motion or the pitches or the intervals between the pitches, pitch range, tension and release, continuity and coherence and shape (Brink, 1997:301). Melody is one of the absolute quintessential elements of music (Limb, 2006:441).

2.6 COMPUTERIZED-ADAPTIVE TESTS VS. SELF-ADAPTED TESTS

The use of computers for administering and scoring music listening tests has increased dramatically in recent years (Vispoel & Coffman, 1994:27).

When a person is subjected to a music listening test, a momentary lapse in attention can lead to an incorrect response because each item is played only once. This problem is less serious in visually administered tests because the items may be reread as many times as desired before responding (Vispoel & Coffman, 1994:27). The high degree of concentration required to perform well on listening tests is difficult to maintain over a long period of time and quickly tires the subject/s The repetitious nature of many music tests (e.g. indicating whether each of 30 consecutive pairs of tones is the same or different) frequently compounds fatigue problems with effects of apathy and boredom. To reduce these problems, music test developers usually limit administration time to one hour or less. This practice, however, sometimes reduces the reliability and validity of individual sub-tests in aptitude and achievement batteries to unacceptably low levels (Vispoel & Coffman, 1994:27). Computerized-adaptive test procedures have been greeted with enthusiasm by many music test developers because such procedures provide a vehicle for significantly enhancing the reliability and validity of music listening tests while maintaining or even reducing test length and administration time (Vispoel & Coffman, 1994:27).

The major advantage of computerized-adaptive music listening tests was found to be its efficiency (Vispoel & Coffman, 1994:43). When a fixed measurement precision termination and fixed length stopping criterion was used, the computerized-adaptive test required less than half the administration time that the self-adaptive test required. This gap in efficiency occurred because the self-adaptive test required both additional items to attain the precision criterion and additional time for examinees to choose the difficulty levels of items. These findings indicate that at fixed lengths the self-adaptive tests inefficiency resulted predominantly from the time subjects spent selecting item difficulty levels. At the fixed-reliability criterion, however, the self-adaptive tests' inefficiency was largely due to the time needed to administer additional items (Vispoel & Coffman, 1994:43).

What this pattern of correlations suggests is that self-adaptive tests may yield more construct valid scores than computerized-adaptive tests (Vispoel & Coffman, 1994:44). The reason for this is that self-adaptive tests might reduce the influence of debilitative motivational processes (excessive anxiety or arousal, self-preoccupying worry, self-doubts, etc.) and promote the influence of facilitative ones (attention to tasks, optimal arousal, positive self-regard, etc.). Under these circumstances, a self-adaptive test score would better reflect an individual's maximum performance level and thereby provide a more accurate or construct valid indicator of the ability of interest (Vispoel & Coffman, 1994:44).

If self-adaptive tests promote positive attitudes and reduce the influence of debilitative motivational factors on test performance, then the consequences of taking such tests may be more favourable than those resulting from other testing procedures (Vispoel & Coffman, 1994:46). Self-adaptive tests, for example, could make assessment experiences more pleasant for many subjects, and this in turn might motivate them to expend greater effort and persistence in accomplishing future tasks in the assessed content domain. If this is the case, then self-adaptive tests might be particularly beneficial for assessing music skills due to the motivational problems often associated with learning music related tasks (unfavourable attitudes, internal locus of control for failure, high performance anxiety, etc.). Therefore one may conclude that computerized-adaptive tests provide greater efficiency and self-adaptive tests provide greater potential motivational benefits (Vispoel & Coffman, 1994:46).

For the purpose of this study, the researcher did not make use of a computerized test as this would imply the need for extra equipment to present the test and as mentioned before, this may limit the future use of the test in the South African context as service delivery in South Africa is characterized by limited resources and facilities (Johnsen, 1998:217).

2.7 MUSIC PERCEPTION IN THE SOUTH AFRICAN CONTEXT

Music includes a considerable variety of structural elements presented in manifold combinations and styles occurring within a cultural context (Leal *et al.*, 2003:826). Some aspects of music are culturally based, and one might well expect to see differences due to this in results from participative assessments that test emotional responses (Medel Medical Electronics, 2006:1). Research by Chasin and Russo (2004:39) found that individuals of the same culture with normal or corrected-to-normal hearing tend to experience melody, harmony and key in a similar manner – that is, sensitivity to these constructs does not require formal training.

The South African music industry is founded upon a rich and resourceful cultural heritage which is borne by a conglomerate of cultures with strong elements of demographic diversity, cross-cultural influences, social development and emotionally deep-rooted musical development and therefore this multi-racial, multi-cultural demography creates a diverse, yet richly creative environment with unique musical products (De Villiers, 2006:1).

South Africa is very diverse, with many native African ethnic groups as well as European and Indian people (Barrett, 2007:11). In the South African context, cultural and musical identities are often intertwined with language, racial and even tribal identities (Joseph & Van Niekerk, 2007:488). The South African music scene includes both popular and folk forms. Early South African music was brought by Christian missions that provided the first organized musical training in the country. Since the pre-colonial period, traditional music was performed on social occasions such as communal work and during ritual ceremonies such as marriages or funeral rites. Many African ceremonies go hand in hand with music performance and music is used as a carriage that embodies relevant messages (Wanyama, 2006:1). African music is functional in that whenever it is performed there is a specific role it usually accomplishes. The content of music is dictated by the day-to-day occurrences in the respective societies. Technological development, growth of towns and industries has contributed to changes in ways of life in African communities and gave rise to new compositions with new themes together with new performance styles (Wanyama, 2006:2).

South African popular music began in 1912 with the first commercial recordings, but only began booming after 1930 when Gallo Record Company sent several South African musicians to London for recordings. Gallo Record Company remains the largest and most successful music label in South Africa. In the early twentieth century, the Zionist Christian churches spread across South Africa and incorporated African musical elements into their worship – hence the advent of South African gospel music (Stewart, 2001:2) and in 1936 the Stellenbosch University Choir, which is the oldest running choir in the country, was formed.

Afrikaans music was primarily influenced by Dutch folk music styles along with French and German influences in the early twentieth century. In this era string bands led by a concertina were popular as were elements of American country music. Afrikaans music is currently one of the most popular and best selling industries on the South African music scene (Senekal & Van den Berg, 2010:99)

In the 1950s the music industry became greatly diversified and included several major labels. The first major style of South African popular music to emerge was pennywhistle jive, also known as kwela. Jazz was also popular during this era. The late 1960s saw the rise of soul music from the United States, followed by the punk rock boom of the United Kingdom and the American disco of the late 1970s (De Villiers, 2006:17).

Since the 1970s, each ethnic group enjoyed its own traditional music. The Sotho traditional music was characterized by the concertina which was replaced in the 1970s with accordion and electric backing bands while the Zulu people adopted the guitar from the Portuguese in the sixteenth century that was central to their musical tradition (Wanyama, 2006:8). Tsonga traditional music showed a largely African style influenced by Latin rhythms whereas the traditional music of the Pedi group is principally based on the harp (Wanyama, 2006:9).

In 1994, South African media was liberalized and new musical styles arose. Kwaito, named after the Amakwaito (a group of 1950s gangsters in Sophiatown) is a style of music similar to hip hop, featuring vocals recited over an instrumental backing with strong bass lines (Oxford, 2010). There was also a dramatic growth in the popularity of Afrikaans music and numerous new young Afrikaans singers attracted large audiences to art festivals such as the *Klein Karoo Nasionale Kunstefees*, *Aardklop* and *Innibos* (Senekal & Van den Berg, 2010:106). Apart from dozens of new songs being introduced into the Afrikaans music market, it became popular for modern young artists to sing old Afrikaans songs on a stage or in a pub with crowds of admirers singing along. The first South African live techno bands also emerged – their music was mainly influenced by European artists but included a unique South African touch.

The 2000s were characterized by kwaito, Afrikaans music (different forms emerging like Afrikaans rock and alternative music) and metal that continued to grow rapidly (Senekal & Van den Berg, 2010:99). The South African music scene has continued to flourish in the 2000s with the music scene focused around four major areas including Johannesburg, Cape

Town, Durban and Bloemfontein where there is a strong sense for actively developing the local talent.

The introduction of the South African Music Awards (SAMA) intended to recognize accomplishments in the South African recording industry and has raised the awareness of local artists and bands. The awards are given in various categories, including album of the year, best newcomer, best male and female artists, etc. South Africa also has several annual music festivals including *Oppikoppi* and *Rocking the Daisies* that cater to different genres and styles of music (Allen, 2008:31).

As seen from the above, the story of South African music is one of dialogue with imported forms and varying degrees of hybridization over the years. From the earliest colonial days until the present time, South African music has created itself out of the mingling of local ideas and forms with those imported form outside the country, giving it all a special twist that carries the unmistakable flavour of the country. It is however, sad that South Africa does not have a functional archive of all its previous music. This is due to factors such as lack of care of master tapes, ineffective storage practices, and fire. Also, record companies did not keep a library of the recordings they released and there was no effective national copyright library that collected sound recordings published in South Africa (Allen, 2008:29).

2.8 CONCLUSION

Hard-of-hearing musicians have long complained about the poor sound quality they experience while playing their instruments or when listening to music through hearing aids. Indeed, many non-musicians also complain of the reduced sound quality of music heard through their personal amplification, to such an extent that hearing aid users often prefer to remove their hearing aids when listening to music (Wessel *et al.*, 2007:1; Chasin, 2003b:36).

The field of Audiology acknowledges the value of musical perception in quality of life (Spitzer *et al.*, 2008:57); the experience of music is complex and wide-ranging, and may be an important enhancer of quality of life for both normal hearing and hearing impaired participants. However, great differences in terms of musical background, listening habits, musical tastes and involvement reflect the diverse universe of listening experiences, which cannot be summarized by means of tests and questionnaires (Luis *et al.*, 2007:682).

The effects of hearing aid processing on musical signals and on the perception of music have received very little attention in research (Wessel *et al.*, 2007:1). Though listeners and musicians who have a hearing loss are no less interested in music than normal hearing listeners, there is evidence that the perception of fundamental aspects of Western musical signals, such as the relative consonance and dissonance of different musical intervals, is significantly altered by hearing impairment. Measuring instruments such as the *Articulation Index* and the *Speech Intelligibility Index* can be used to predict intelligibility from the audibility of speech cues across all frequencies and a variety of objective tests of speech comprehension are used to measure hearing aid efficiency. There is, however, no standard metric for a patient's perception of music (Wessel *et al.*, 2007:1). Moreover, persons with a hearing loss are less consistent in their judgments about what they hear than normal hearing listeners, and individual differences in performance among listeners having similar audiometric thresholds make it difficult to predict the perceptual effects of hearing aid processing on musical stimuli (Wessel *et al.*, 2007:1). These factors, combined with the differences in the acoustical environments in which different styles of music are most often presented, underline the importance of individual preferences in any study of the effects of hearing aid processing on the perception of music. Therefore, the researcher developed a test of music perception for persons with hearing aids comprising rhythm, timbre, pitch and melody recognition and it is hoped that this test will provide a method to measure music perception in hearing aid users that is efficient and will contribute to improved hearing aid fittings as well.

2.9 SUMMARY

In this chapter music perception is defined. The physiological effects of music are discussed and detailed descriptions of current music perception tests are provided. The researcher described the development of the music perception test compiled for this study and concluded with an overview of music perception within the South African context.

Chapter 3

NON-LINEAR FREQUENCY COMPRESSION IN HEARING AIDS

Chapter aim: This chapter serves as a theoretical basis for the empirical research and provides a critical evaluation as well as interpretation of the relevant literature. The focus is on non-linear frequency compression hearing aids as well as on other frequency lowering hearing aids described in the literature.

3.1 INTRODUCTION

In the current consumer-driven era of health care, health professionals need to be able to demonstrate to both the community and resource providers that the services they provide have a positive impact on their clients' functional status and quality of life (Uriarte, Denzin, Dunstan, Sellars & Hickson, 2005:384). It is not surprising that there is ongoing concern among providers of hearing health care about the effectiveness of hearing aid fittings (Cox, 2005:420). Currently, a lot of service providers are unaware of the existence of frequency lowering hearing aids while others fit these hearing aids without proper knowledge or scientific evidence of their efficacy. There is a need to promote practitioners' ability to recognize the potential of promising new treatments and technologies, like non-linear frequency compression hearing aids, and to apply it appropriately (Cox, 2005:420).

Evidence based practice offers a new perspective on the responsibilities of researchers, teachers, learners, and practitioners like audiologists as well as hearing aid acousticians. It recognizes that in an age of information explosion health care practitioners should acquire skills that allow them to rely more on their own resources and less on traditional sources of authority evaluating new developments and treatments; else they may not maintain currency of knowledge. Evidence based practice is an orientation that promotes continuous patient-driven revising of treatment protocols to incorporate new knowledge about treatment effectiveness (Cox, 2005:420) that would result in more accountable hearing aid fittings to clients.

Several studies were conducted focusing on various frequency lowering hearing aids and their benefit for speech perception. There is, however, still a limitation in the specific provision of reliable fitting with frequency lowering hearing aids and their amplification of music stimuli. This study addresses the principles of evidence based practice to ensure that all treatment options should be data based (Cox, 2005:422) in terms of collecting scientific information on the influence of non-linear frequency compression hearing aids on music perception.

3.2 FREQUENCY LOWERING TECHNOLOGY AND TERMINOLOGY ISSUES

The loss of audibility of high frequency sounds often compromises speech understanding and the appreciation of music as well as nature's sounds (Kuk *et al.*, 2006: par. 2). In recent years, commercially available hearing aids have employed a variety of frequency lowering strategies for high frequency information to be moved to a lower frequency region as an option for clinical use (Glista & McDermott, 2008:2; Scollie *et al.*, 2008:2; McDermott & Knight, 2001:121). The target beneficiaries of this technique are usually people with a severe to profound hearing loss in the high frequencies who cannot benefit form conventional amplification (Kuk *et al.*, 2006: par. 3) but other degrees of hearing loss are also considered today.

Three current frequency lowering strategies have been mentioned in Chapter 1, namely proportional frequency compression, linear frequency transposition and non-linear frequency compression. Despite the publication of excellent reviews of frequency lowering strategies, some of the terminology for the different processing schemes is often used interchangeably and terminology is not standardized (Glista, Scollie, Bagatto, Seewald, Parsa & Johnson, 2009:633). Some researchers used the term "frequency shifting" as the generic term for all devices that utilize frequency lowering (Erber, 1971:530), while others referred to these devices as "frequency lowering" devices (Braida, Durlach, Lippman, Hicks, Rabinowitz and Reed (1978:102). Furthermore, proportional frequency compression incorporates both transposition and compression strategies, and are referred to by some authors as a frequency transposition device and by others as a frequency compression device (Ross, 2005: par. 4). All these frequency lowering strategies mainly differ from one another along three dimensions (Glista & McDermott, 2008:2; Scollie *et al.*, 2008:2):

- whether the frequency lowering processing is always on (i.e. unconditional lowering) or is time-varying and only active under certain conditions (i.e. conditional lowering);
- whether the frequency lowering is achieved by shifting frequencies down (do the shifted frequencies overlap with the un-shifted frequencies, i.e. transposition) or narrowing the output bandwidth (i.e. compression); and
- whether the lowering is done for all frequencies (i.e. linear or proportional) or is restricted to only a portion of the frequency spectrum (i.e. non-linear or non-proportional).

For the purpose of the current study, **proportional frequency compression** refers to the reduction of the frequency bandwidth by lowering all the spectral components of the signal by a constant factor, **linear frequency transposition** refers to the lowering of the high frequency components of the signal by a fixed amount and **non-linear frequency compression** refers to the reduction of the bandwidth by only lowering the high frequency components of the signal in increasing degrees. **Frequency lowering** will be used as the generic term to refer to all the above-mentioned strategies.

3.3 PREVIOUS FREQUENCY LOWERING HEARING AIDS

Various frequency lowering techniques have been incorporated in frequency lowering hearing aids before. These early frequency lowering circuitries included (Braida *et al.*, 1978):

- Frequency shifting: All spectral components of the entire frequency spectrum are shifted downwards by a fixed displacement.
- Slow-playback: Pre-recorded sounds are replayed at a slower rate than the original signal, and each spectral component is lowered in frequency by a multiplicative factor equal to the slowdown factor.

- Time-compressed slow-playback: Essentially the same as slow-playback, but speech is compressed in time, deleting segments periodically, deleting successive pitch periods of voiced sounds, and deleting segments according to phonological rules.
- Transposition: Only high frequency components of the frequency spectrum are shifted downwards by a fixed displacement.
- Vocoding: Bandwidth reduction is achieved by filtering speech through a low-pass filter. The vocoder transmits a signal that is descriptive of the vocal sound source and the fundamental frequency of voiced sounds.
- Zero-crossing-rate division: Speech is filtered into four pass-bands, and the resulting signal is processed to achieve a frequency spectrum band reduction by a factor of two.

A relatively simple form of frequency lowering is to shift each frequency component of the sound by a constant factor (McDermott & Dean, 2000:353). A possible advantage of this form of transposition is that ratios among the frequency components of the signal are not changed by the processing. This may be beneficial for speech perception because frequency ratios (such as that between the first and the second formants) convey important information. On the other hand, an obvious disadvantage is that the overall pitch of the speech signal is also lowered causing, for example, a female speaker to sound like a male speaker. However, in contrast to some other frequency-lowering techniques, transposition by a uniform factor provides a high quality signal that could plausibly provide additional speech information to listeners with steeply sloping audiograms (McDermott & Dean, 2000:353).

The first attempts at frequency lowering were made well before non-linear and digital technology was applied to hearing aids (Kuk *et al.*, 2006: par. 4). One early strategy used non-linear modulation techniques to shift high frequency speech components to a lower frequency range (Simpson *et al.*, 2006:619). The downward shift was typically disproportionate, meaning that frequency ratios contained in the spectral information were not preserved during processing. The resulting signals were mixed with those obtained form lower frequencies (Simpson *et al.*, 2006:619). Another attempted scheme in the sixties implemented disproportionate frequency shifting in which high frequency energy was passed through a non-linear modulator that converted it into low frequency noise. Several studies of these early types of frequency lowering methods reported little success in benefiting speech understanding. This may have happened for a variety of reasons including that much of the information regarding the spectral shape of the incoming signal was lost as a result of the processing technique. As mentioned, these methods did not preserve frequency ratios in the high frequencies when they were shifted to lower frequencies. In addition, they may have provided some additional high frequency information at the expense of other perceptual cues by overlapping the shifted and un-shifted signals (Simpson *et al.*, 2006:619).

About ten years ago a body worn transposer hearing aid was introduced – this was met with little acceptance, possibly because of cosmetic reasons (Ross, 2000: par. 3). It differed from previous attempts in that it not only electronically shifted the higher frequencies to lower ones, but also compressed them in the frequency domain (frequency compression) while leaving, if desired, the lower frequencies untouched. Moreover, it operated in a way that kept the ratio between adjacent sounds intact. If an incoming speech sound, like the broad spectrum sound [s], had some energy peaks at 3 kHz, 4 kHz, 6 kHz and 8 kHz, and the frequency compressor used a factor of two, then all the peaks would be halved in frequency before being delivered to a listener. Consequently these energy peaks of [s] would now be at 1.5 kHz, 2 kHz, 3 kHz and 4 kHz respectively, possibly rendering at least some of the peaks audible for a person with a high frequency hearing loss (Ross, 2000: par. 3). This kind of proportionate shifting is very important for speech perception, since we know that perception is less affected by acoustic variations in the speech signal when the ratio relationship between energy peaks is maintained (Ross, 2000: par. 4). The aid designed ten years ago now has newer versions. These system works mainly by analyzing incoming speech signals and determining whether the sounds are voiced or voiceless. If voiceless, which signifies a high-frequency consonant, the incoming sound is frequency compressed to the pre-set degree. When the next sound comes along, usually a vowel in the normal syllabic sequence, the aid reverts to its normal amplification pattern. The voiced sounds are simply passed through and processed as determined during the initial programming. When the next voiceless sound is detected, the frequency compression circuit is again activated (Ross, 2000: par. 7). In effect, what is happening in this alternating process is that all the high frequency consonants are squeezed and shifted lower in frequency, leaving the vowels and lower frequency consonants untouched (Ross, 2000: par. 8).

More recent frequency lowering strategies included proportional frequency compression and approaches that 'sharpen' the spectrum of the transposed sound or the various transposed features. Although these approaches are significantly more complex than the earlier attempts and they all resulted in better aided thresholds, their acceptance has been relatively limited (Kuk *et al.*, 2006: par.5). Whilst lowering the frequencies, these methods also altered other aspects of speech known to be important for perception. Some of these approaches created unnatural sounding speech, distorted gross temporal and rhythmic patterns, and extended durations (slow playback) of the speech signals. In the slow playback method, segments of the speech signal were recorded and then played back at a lower speed than employed for recording (Simpson *et al.*, 2006:620; Parent *et al.*, 1997:355). In these devices, the activation of frequency lowering is dependent upon the incoming signal. An incoming signal dominated by components at frequencies above 2.5 kHz is shifted down by a factor that is programmable for each listener. If the input signal is not dominated by frequencies above 2.5 kHz, then all signals are amplified with no frequency lowering (Simpson *et al.*, 2006:620). Other aids created reversed spectrums (amplitude modulation based techniques) which is difficult to even recognize as speech by experienced listeners (Kuk *et al.*, 2006: par. 6). Proportional frequency shifting offers the advantage that the ratios among frequency components are not changed by the processing (Simpson *et al.*, 2006:620).

Earlier, Turner and Hurtig (1999:884) conducted a study with a proportional frequency compression scheme which preserved the natural ratios between the frequency components of speech and also generally preserved the temporal envelopes of the signal. Results indicated significant improvements in speech recognition for hearing impaired listeners with most of the participants demonstrating a benefit for hearing material spoken by female speakers versus male speakers (Turner & Hurtig, 1999:885). In another study conducted with a frequency compression scheme, the scheme provided perceptual performance superior to the performance of conventionally fitted hearing aids for words presented at a moderate level in quiet conditions (Simpson *et al.*, 2005:289). The scheme divided incoming signals into two broad bands based on a chosen cut-off frequency ranging from 1.6 kHz to 2.5 kHz. Signal components below the cut-off frequency were amplified with appropriate frequency shaping and amplitude compression but without frequency lowering. Signal components above the cut-off were compressed in frequency in addition to amplification. The frequency compression was non-linear and applied progressively larger shifts to components having increasingly high frequencies (Simpson *et al.*, 2006:620). A possible advantage of the scheme is that there is no spectral overlap between the shifted and un-shifted signals. This results in the first formant and most of the second formant frequency range being preserved, since the device does not shift low and mid frequency information. A possible disadvantage of the scheme is that it does not preserve frequency ratios for these high frequencies that are compressed. It leaves, however, the possibility that the perception of certain sounds, such as music, may be affected adversely (Simpson *et al.*, 2006:620). Specifically, these hearing aids provided better recognition of monosyllabic words than conventionally fitted hearing aids, greater high frequency sensation levels were achieved and half of the subjects obtained a significant phoneme score increase with the other half showing no difference in score (Simpson *et al.*, 2005:282). In yet another study, patients also were found to benefit from digital frequency compression when speech is presented against background noise and subjective ratings revealed a tendency for increased ease of communication with digital frequency compression hearing aids (Gifford *et al.*, 2007:1200).

Despite the recent use of digital signal processing techniques in frequency lowering, artefacts and unnatural sounds were still unavoidable (Kuk *et al.*, 2006: par. 7). Some reported that the transposed sounds are 'unnatural', 'hollow or echoic' and 'more difficult to understand'. Another commonly reported artefact is the perception of 'clicks', which many listeners find annoying. Thus, despite its potential for speech intelligibility improvement with extensive training, many adults found it difficult to accept frequency lowering hearing aids (Kuk *et al.*, 2006: par. 7).

A minimum of artefacts or unnaturalness will result if the frequency lowering method retains the relationship of the original frequency components in the final signal (Kuk *et al.*, 2006: par. 9). Preferably, the relationships of the harmonic components should stay the same, the spectral transitions should move in the same direction as the original un-transposed signal, and the segmental-temporal characteristics should stay untouched. One should not remove or sacrifice any acoustic cues that listeners use before frequency lowering. In addition, the processed speech signal should retain the extra-linguistic (prosodic) cues such as its pitch, tempo and loudness. Otherwise, it will initially make it more difficult for listeners to accept the new sound images and therefore lengthen training and relearning time (Kuk *et al.*, 2006: par. 9). One criterion is to lower only the frequencies that are necessary to be lowered. For example, if someone has aidable hearing up to 3 kHz, one should only lower sounds above 3 kHz. This has the advantage of focusing only on relevant sounds (Kuk *et al.*, 2006: par. 10). Another criterion is to apply the 'right' amount of processing for the individual. This is because the more aggressive the lowering, the more unnatural the sound perception becomes. A conservative or less aggressive approach will minimize the disturbance of the original signals and avoid any potential interaction between the original signals and the processed ones. A final criterion is to preserve the temporal structure of the original signal in order to retain any transition cues. This implies that the frequency lowering system should have the flexibility and specificity to meet the individual wearer’s needs (Kuk *et al.*, 2006: par. 12).

So far, hearing aids incorporating frequency lowering have not found widespread acceptance and has produced mixed findings (Munro, 2007:15; Moore, 2001a:30). However, promising results have been found in some studies of commercially available devices. The limited benefit demonstrated in studies so far may partly have occurred because the frequency lowering hearing aids have been fitted to patients without clear knowledge of the extent of the dead regions (Munro, 2007:15; Moore, 2001a:30). Also, when comparing the different approaches, large differences in implementation, resulting in differences in sound quality and potential speech understanding benefit are apparent (Glista & McDermott, 2008:2). Clearly, more research is needed in this area (Moore, 2001a:30) and it is important to point out that providing audibility of high frequency information to listeners with severe to profound hearing losses remains a controversial topic (Bagatto *et al.*, 2008: par. 2).

Currently, no studies exist that attempts a comparison between the various strategies. However, some evidence does exist to support the use of some forms of frequency lowering devices (Scollie, *et al.*, 2008:2). Frequency transposition and frequency compression technology are the two main types of frequency lowering technologies available today (Glista, Scollie, Polonenko & Sulkers, 2009: par. 2; Bagatto *et al.*, 2008: par. 3). For the purposes of this study, the researcher will discuss these two frequency lowering technologies in more detail in the sections to follow.

3.4 FREQUENCY TRANSPOSITION

Frequency transposition shifts the signal down the frequency axis by a fixed amount (Glista *et al.*, 2009:633; Bagatto *et al.*, 2008: par. 3). All frequency transposition algorithms identify a frequency above which they transpose (Kuk, 2007: par. 2). This frequency is called the start frequency and the region of sounds that would be transposed is called the source. In general, sounds in this region will be lowered in frequency (e.g. from 4 kHz to 2 kHz). Sounds below the start frequency are amplified based on the individual's degree of hearing loss at those frequencies. Transposition moves sounds from the source region to a 'target' region immediately below the start frequency. The transposed sounds are mixed with the original sounds and receive amplification appropriate for the frequency (Kuk, 2007: par 3).

The main disadvantage of frequency transposition is that the original spectrum is substantially preserved (Jerger, 2009:288). Only a limited range of high frequencies is superimposed on the original spectrum and therefore the audibility of high frequency consonants is aided without serious distortion of the vocal characteristics of the talker. Another disadvantage is the difficulty in avoiding artefacts when the transposed signal is added to the original signal (Jerger, 2009:288). An additional problem with transposition is that it does not reduce the bandwidth of the hearing aid; it only shifts the signal down. This creates very strong distortions when the transposed frequency is greater than the signal frequency (Davis, 2005: par. 2).

Various frequency transposition hearing aids have been reported. Most of them could separately adjust the degree of transposition for unvoiced speech from that of voiced speech and suggested that frequency transposition is beneficial for persons with a high frequency hearing loss (Sakamoto, Goto, Tateno & Kaga, 2000:327). One relatively early frequency transposition scheme operated by detecting whether the incoming signal was above or below a particular high frequency (Glista & McDermott, 2008:2). If the signal was above this frequency, it activated the frequency transposition and shifted all frequencies within the amplified sound. One weakness of this scheme is that high frequency inputs are difficult to detect reliably, especially in situations with competing noise. Furthermore, enabling and disabling transposition can produce distracting artefacts that are audible to some hearing aid users (Glista & McDermott, 2008:2).

The AVR Transonic FT-40 was the first commercially available transposition device (Glista *et al.*, 2009:633). This device used a processing unit to analyze incoming signals and apply frequency lowering to sounds with predominantly high frequency energy (above 2.5 kHz). Early studies indicated mixed outcomes with the body-worn FT-40 in adults and children, concluding that the FT-40 system was suitable for a select group of listeners. AVR Sonovations later introduced the ImpaCt BTE hearing aid (Glista *et al.*, 2009:633). McDermott and Knight (2001) found limited benefit attributable to the ImpaCt transposition signal processing when evaluated on adult listeners. This could be contributed by factors like differences in participants' age, training, and audiometric configuration. The ImpaCt has also been evaluated in children, suggesting that a significant word recognition benefit could be achieved for children with severe hearing loss when using transposing hearing aids, in comparison to conventional ones (Glista *et al.*, 2009:633).

Overall, most previous transposition trials were of limited success and the disappointing results may be related to the methods of frequency transposition, as well as to the lack of ability at that time to diagnose the presence and extent of dead regions (Robinson *et al.*, 2007:294). Many previous transposition schemes used unconditional transposition. It was found that the perception of semi-vowels and nasals was degraded using an unconditional transposition scheme, but this was prevented when conditional transposition was implemented (Robinson *et al.*, 2007:306). When conditional transposition was implemented, which meant that only consonants with significant high frequency information were transposed, a benefit for consonant detection was perceived (Robinson *et al.*, 2007:306).

Several years ago Widex Hearing Aid Company reintroduced frequency lowering as an optional signal processing feature in its Inteo family of hearing aids (Kuk, Keenan, Korhonen & Lau, 2009:466). This feature uses linear frequency transposition (called the Audibility Extender) to lower information above a programmable start frequency to a lower frequency region. The start frequency can be selectively determined for each individual, based on the hearing loss configuration (Auriemmo, Kuk, Lau, Marshall, Thiele, Pikora, Quick & Stenger, 2009:291). In this algorithm, the most prominent peak located in the source octave (above start frequency) is identified and transposed linearly by one octave. Sounds below the start frequency are left amplified. The transposed signal is then band-pass filtered around the transposed peak with a bandwidth of one octave to limit any potential masking effects. Finally, the transposed sounds are amplified and mixed with the original signal as the final output (Kuk *et al.*, 2009:466).

The linear frequency transposition algorithm used in the device referred to above is unique in several ways (Kuk *et al.*, 2009:466): First, the amount of frequency displacement at any instant in time is directly related to the location of the highest spectral peak of the original signal in the source octave. This was done to ensure that the harmonic relationship of the transposed and the original signal remains at exactly one octave for the most dominant frequency. This could preserve the naturalness and pleasantness of the output signal delivered to the listener. Second, the processing is unconditional, that it, it is active all the time. This ensures that the lowering of any high frequency information is not dependent on the reliability of any activation criteria such as voicing detection. These design criteria may help to minimize any discontinuities in the output signal, reduce artefacts and provide consistent processing (Auriemmo *et al.*, 2009:291; Kuk *et al.*, 2009:466).

In a study focusing on this technology, nine normal hearing adults with a simulated hearing loss at and above 1.6 kHz were tested on the identification of transposed voiceless consonants before and after they completed three 15 minutes self-paced training. It was found that transposition improved the identification scores of the stimuli by 14.4% over non-transposed stimuli after 30 minutes of training with the transposed stimuli (Kuk *et al.*, 2009:466). Another study by Auriemmo *et al.*, (2009) examined the efficacy of linear frequency transposition in 10 children with severe to profound hearing loss at and above 3 kHz (Kuk *et al.*, 2009:467). Phoneme recognition and articulation performance were compared among the children’s own hearing aids and the study hearing aids with and without linear frequency transposition. The results indicated significant improvements in vowel and consonant recognition and accuracy of fricative production after six weeks of linear frequency transposition use, and suggest that linear frequency transposition is a potentially useful feature for school-aged children with a severe to profound high frequency sensory neural hearing loss (Auriemmo *et al.*, 2009:301; Kuk *et al.*, 2009:467). They also examined subjective preferences of these children for linear frequency transposition and the impact of linear frequency transposition on awareness of environmental sounds. Results indicated that for speech stimuli, children report the linear frequency transposition program as preferred or equally preferable to the default program 60% of the time at the initial fitting. This preference remained relatively stable after three and six week's use of the linear frequency transposition. This was not the case for adult users of linear frequency transposition who initially preferred the default program over the transposition and whose preference changed only after two weeks of use time. Awareness of environmental sounds was significantly improved after six weeks of use of linear frequency transposition compared to the own hearing aid (Auriemmo *et al.*, 2009:301).

In yet another study with linear frequency transposition it was found to improve nonsense syllable identification, especially syllables containing fricatives, in quiet and also in noise. On the other hand, the speech benefit was not apparent for all phoneme classes at the initial visit. For some phonemes there was a slight but non-significant decrease in identification which was temporary in nature and resolved within two months. Studies also indicated that linear frequency transposition significantly improved hearing of everyday sounds[12] and the identification of consonants (Kuk *et al.*, 2009:475). Kuk *et al.*, (2009:476) further examined consonant identification in quiet and in noise with the linear frequency transposition hearing aids. It is important to remember that the objective of frequency lowering is not to improve speech understanding in noise but to provide audibility of the unreachable high frequency information as a lower frequency substitute. Rather than removing parts of the input signal like a noise reduction algorithm or a directional microphone, a frequency lowering algorithm adds to the overall audible input to the ear (Kuk *et al*, 2009:476). This may result in a louder output and some even speculated that it could lead to a poorer performance in noise. Their study however concluded that linear frequency transposition does not make speech understanding in noise more difficult, and that the benefit of linear frequency transposition in noise remains similar to that in quiet environments (Kuk *et al.*, 2009:476).

The same technology was evaluated with thin-tube, open-ear fittings and showed improved consonant recognition, vowel identification and perception of every day sounds (Kuk *et al.*,

[12] Include sounds like bird songs, warning signals such as alarms and timers, etc.

2007:62). Several reasons why this algorithm may result in a more positive outcome than those reported previously include (Kuk *et al.*, 2007:60):

- Sounds are transposed by one octave. This means that in a high frequency hearing loss the transposed sounds will fall on the slope of the audiogram where survival of the hair cells and neurons may be more ensured. Furthermore, recent studies showed that frequency discrimination around the slope of the audiogram is more sensitive than at other regions in people with a steeply sloping hearing loss. It is logical to speculate that the transposed sounds will have the highest likelihood of being utilized.
- Because the transposition does not alter the temporal and spectral structures below the start frequency, the speech cues within the original sound would be better preserved. This minimizes the extent of distortion and the potential degradation of sound quality and speech intelligibility.
- Because people fitted with a thin-tube, open-ear device in general have residual hearing up to 2 kHz to 3 kHz, the start frequency for transposition could be high (4 kHz). This would leave much of the original sounds unaltered and minimize the amount of overlap of the transposed sounds on the original sounds. This may better preserve the sound quality and lead to a higher acceptance for the transposed sounds.

It needs to be emphasized that the above performances was noted when the subjects were initially fitted with the default settings without additional fine tuning to meet the wearer's hearing needs. Furthermore, no experience with the transposed sounds was provided prior to the study. With additional experience and fine tuning, one would have considered the individual hearing needs when setting the optimal transposition parameters. This could further improve the preference for linear frequency transposition technology (Kuk *et al.*, 2006: par. 41).

3.5 NON-LINEAR FREQUENCY COMPRESSION

While frequency transposition shifts the signal down the frequency axis by a fixed amount, non-linear frequency compression compresses the output bandwidth of the signal by a specified ratio (Bagatto *et al.*, 2008: par. 3). The advantage of frequency compression is that it more closely reflects the familiar octave structure of the frequency scale (Jerger, 2009:288). If, for example, each frequency is shifted by a proportion of 0.5, then 4 kHz becomes 2 kHz, 3 kHz becomes 1.5 kHz, 2 kHz becomes 1 kHz, and so forth. This avoids the problem of the negative frequencies resulting from linear transposition, but the problem resulting from the downward shift of the fundamental frequency of voicing remains (Jerger, 2009:288).

Frequency compression is an innovative solution to the challenge of poor perception of high frequency sounds and with this technique, it is possible to 'match' the bandwidth of the incoming speech signal to the damaged ear's limited band of greatest sensitivity, rather than attempting to force the damaged high frequency sensory units to 'respond' (Davis, 2001: par. 4). In comparison, frequency compression reduces both the frequency and the bandwidth by a pre-set ratio. Due to the fact that the spectrum is 'squeezed' by frequency compression, operating in real-time requires a complex algorithm that maintains the critical information (Davis, 2005: par. 3). A form of frequency compression which is widely used today is non-linear frequency compression (Bagatto *et al.*, 2008: par. 2) and as the hearing aids used in the current study consisted of a non-linear frequency compression algorithm, this technology will be described in more detail below.

Recently, a product named SoundRecover (first implemented in Phonak Naida instruments), was developed. SoundRecover is a multi-channel, non-linear frequency-compression algorithm designed specifically for hearing aid wearers who have difficulty hearing key high-frequency speech information such as the fricatives [f] and [s] (Glista & McDermott, 2008:1; Nyffeler, 2008b:22). This non-linear frequency compression algorithm extends the audible range by compressing and shifting otherwise inaudible high frequencies into an adjacent lower frequency area with less cochlear damage – this broadens the bandwidth for natural production of sounds without them being harsh or tinny and avoids the production of annoying artefacts (McDermott *et al.*, 2010:34; Stuermann, 2009:1; Glista & McDermott, 2008:3). It further does not involve any mixing of frequency-shifted signals with other signals already present at lower frequencies and the processing does not depend on detecting specific features of incoming sounds, such as the dominant peak frequency in the source octave, as is the case with linear frequency transposition (McDermott, 2010:1). Instead, all frequencies above a so-called cut-off frequency are lowered by a progressively increasing amount. The increase in the amount of lowering across frequencies is determined by a second parameter, the frequency-compression ratio. A visual presentation of the difference between frequency transposition and non-linear frequency compression (SoundRecover) is provided in Figure 3-1.

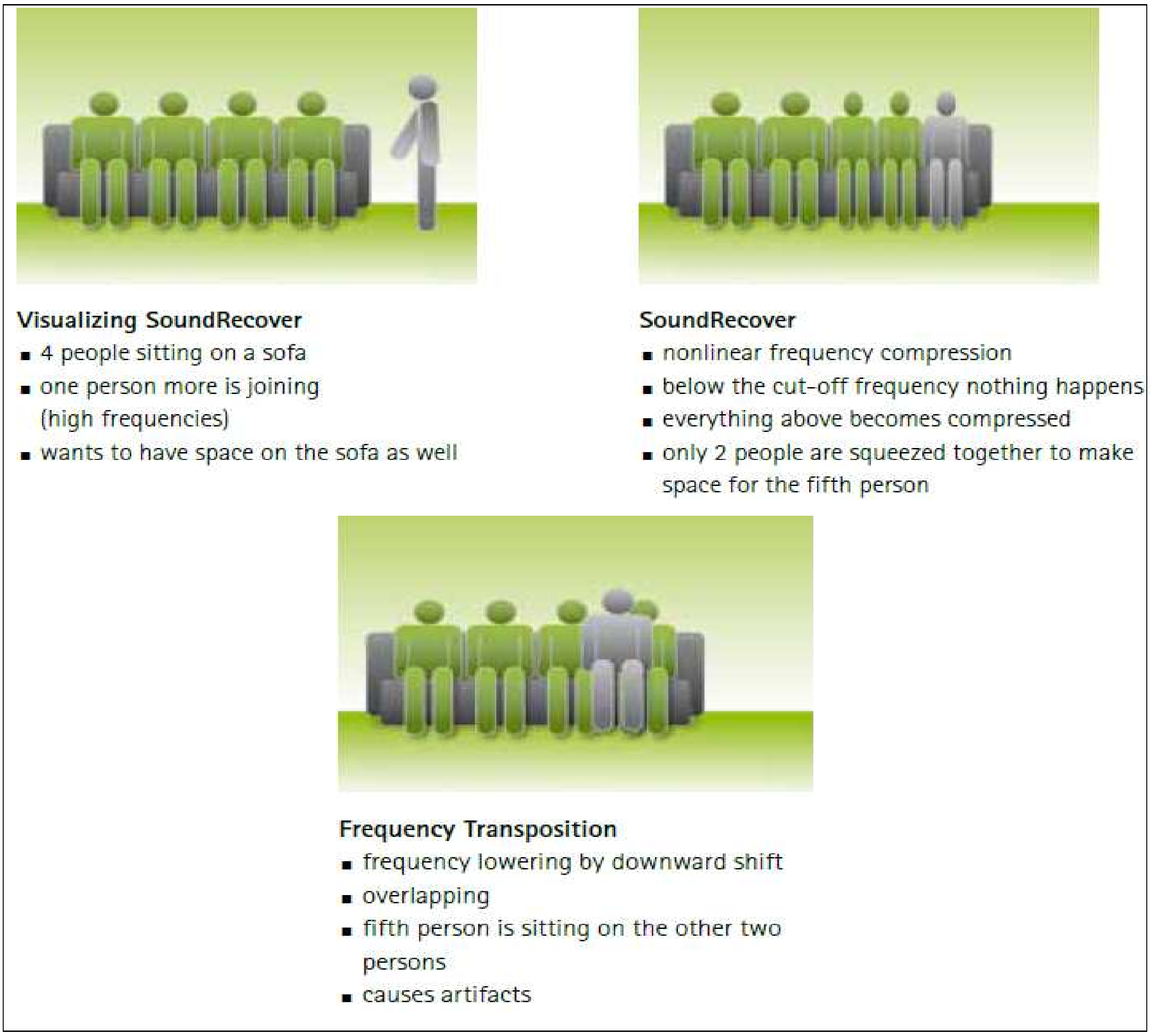


Figure 3-1: Visual presentation of the differences between SoundRecover and linear frequency transposition (Phonak, 2009).

The main differences between frequency transposition and non-linear frequency compression as highlighted in Figure 3-1 are also summarized in Table 3-1 below with specific focus being placed on linear frequency transposition as frequency transposition circuitry and how it differs from non-linear frequency compression.

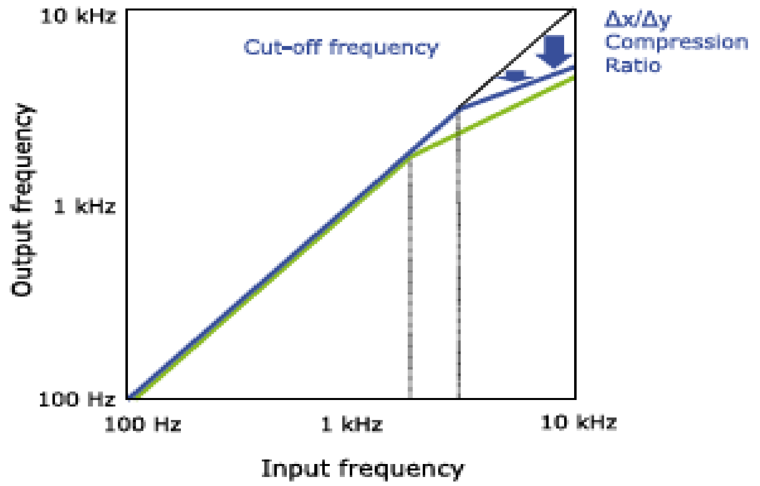
Table 3-1: Main differences between non-linear frequency compression and linear frequency transposition

Non-linear frequency compression	Linear frequency transposition
Compresses the output bandwidth of the signal by a specified ratio	Shifts the signal down the frequency axis by a fixed amount
Non-linear amplification	Linear amplification
Applies a frequency compression ratio to the high frequency band, narrowing it in bandwidth but not mixing it with low frequency energy	Transposed sounds are mixed with the original sounds and receive amplification appropriate for the frequency

From the above it is evident that both non-linear frequency compression and linear frequency transposition shifts the high frequency information to lower frequencies but different procedures are followed to accomplish it – this might have an influence on the quality of the information that the hearing aid wearer perceives.

With the SoundRecover algorithm, digital signal processing is used to separately control non-linear frequency compression in the lower versus higher frequencies (Glista *et al.*, 2008:1). The lower frequency region is uncompressed and normally amplified, preserving natural formant ratios of speech and other sounds and therefore a natural sound quality. The higher frequencies undergo clinician-adjustable non-linear frequency compression processing in increasing degrees to higher input frequencies (Nyffeler, 2008a:2). The amount of compression is limited to ensure that compressed frequencies do not interfere with the frequencies below the cut-off. This also ensures that artefacts are minimized and a clear sound quality is maintained. The initial frequency compression setting is automatically calculated by the fitting software for each wearer and can be easily fine-tuned if needed.

The shape of the non-linear frequency compression function, and therefore the effect on the listener's perception, can be controlled by adjusting two parameters, i.e. the cut-off frequency and the compression ratio (Glista & McDermott, 2008:4). It is important to be able to adjust compression rates individually since the ideal compression rates differ for each individual because each individual has a uniquely shaped auditory filter (Yasu, Hishitani, Arai & Murahara, 2004:62). By adjusting the compression, the quality and intelligibility of speech sounds can be improved for persons with a hearing loss (Yasu *et al.*, 2004:62) and for adult users, both the hearing levels at specific frequencies and the slope of the audiogram across frequencies are taken into account (Glista & McDermott, 2008:3). For calculation of the cut-off frequency, relatively high frequencies are selected if the hearing impairment is mild or the audiogram is flat (McDermott, 2008:3). Lower cut-off frequencies are selected for more severe levels of impairment or for audiograms with relatively steep slopes. The frequency compression ratio is then derived from the cut-off frequency. The compression ratio effectively determines the strength of the frequency compression processing above the cut-off frequency. For example, large compression ratios result in a stronger degree of frequency compression, because a wider range of input frequencies is compressed into a given range of output frequencies (Glista & McDermott, 2008:3). The cut-off frequency and the compression ratio are present within restricted ranges of 1.5 kHz to 6 kHz and 1,5:1 to 4:1 respectively (McDermott, 2010:3). Figure 3-2 displays the effect of the cut-off frequency in the determination of the amount of non-linear frequency compression taking place:



Cut-off frequencies

- Input/Output frequency graph
- frequencies below cut off frequencies remain unchanged
- frequencies above cut off frequencies are compressed
- mild to moderate HL = high cut off frequency, low compression rate
- severe to profound HL = low cut-off frequency, high compression rate

Figure 3-2: Cut-off frequency as parameter that control non-linear frequency compression algorithm (Phonak, 2009:1)

From the above-mentioned figure it is clear that the frequencies below the cut-off frequency remain unchanged while the frequencies above the cut-off frequency are compressed.

In theory, a clinician can strengthen the amount of non-linear frequency compression by providing frequency lowering over a broader band (by using a lower cut-off frequency), or by compressing to a greater degree (by using a higher compression ratio). In actual use, however, the two controls are combined into one, with each adjustment resulting in either stronger or weaker SoundRecover settings via changes to the cut-off frequency and/or the compression ratio (Glista & Scollie, 2009b:1). Besides this, the non-linear frequency compression algorithm is also designed to prevent acoustic feedback and discomfort resulting from excessive loudness due to high levels of high-frequency amplification (Nyffeler, 2008b:22). Specific information about SoundRecover includes (Glista & McDermott, 2008:3):

- it is active all the time (when activated);
- a pre-selected range of high frequencies is compressed, based on the listener's hearing loss;
- no special frequency analysis of incoming signals is required; and
- the frequency compressed output signals do not overlap with lower frequencies.

This non-linear frequency compression algorithm was developed and verified in extensive clinical trials in Australia with severe to profound hearing loss users (Glista & McDermott, 2008:5). Clinical field studies have shown that the use of this algorithm restores high-frequency audibility for speech and environmental sounds resulting in spontaneous user acceptance, quick acclimatization, improvement in perception of the wearer's own voice quality and reduced feedback (Glista & McDermott, 2008:6; Nyffeler, 2008b:22). It was also found to increase the pleasantness of sound in quiet and noisy situations, resulting in a highly satisfactory overall impression (Nyffeler, 2008b:26).

Results of a study by Scollie *et al.*, (2008:2) revealed that adults fitted with non-linear frequency compression hearing aids showed significant objective benefit in understanding high frequency speech sounds. Adults with moderate to severe hearing losses showed greater benefits than adults with steeply sloping losses. In another study, participants showed significant improvement in speech recognition tasks when this algorithm was enabled (Bagatto *et al.*, 2008: par. 16). It is noteworthy that, for persons whose results did not show benefit from this frequency lowering scheme, there was no negative impact on speech intelligibility (Stuermann, 2009:2).

Questions about the sound quality of specific sounds when listened to with non-linear frequency compression revealed that subjects initially found that fricatives sounded different. This may reflect the effect of the non-linear frequency compression on the audibility of high-frequency sounds. Over time, however, the sound quality ratings improved consistently. In addition, subjects rated their own voice sound quality as more pleasant with non-linear frequency compression activated than with their own hearing instruments (Nyffeler, 2008b:24). There also have been extensive field studies with adults and children in Canada and Germany that have shown the benefits of this algorithm and this can be summarized as follows (Glista *et al.*, 2008:1):

- increased detection, distinction and recognition of sounds;
- significant improvement in intonation and overall voice quality;
- improved hearing of high-pitched sounds and better speech understanding (most noticeable for high-pitched talkers such as women and children, softly spoken people, and high frequency sounds such as [s] and [f]); and
- reduced feedback.

In a study where the non-linear frequency compression algorithm was used in a different hearing aid (Phonak Audéo), it resulted in improved speech intelligibility for soft speech in quiet situations and provided significant improvement in noisy environments, particularly after an acclimatization period of four weeks. The general first impression of participants of this frequency lowering algorithm was that sounds were more clear or sharp with the algorithm activated than without it, but remained pleasant (Stuermann, 2009:2). Participants also described their own voices as clearer, not too shrill, but with a pleasant brightness (Stuermann, 2009:2). This study also included assessment of subjective perception of sound quality with non-linear frequency compression by giving participants a remote control to use for choosing between two programs, one with non-linear frequency compression activated and one without non-linear frequency compression. Participants did not know in which program the algorithm was active. Data logging results revealed that the non-linear frequency compression 'active' program was selected 91% of the time (Stuermann, 2009:2).

The preliminary findings of a study by Wolfe, Caraway, John, Schafer and Nyffeler (2009:35) suggest that non-linear frequency compression has the potential to substantially improve acquisition and identification of high frequency speech signals and environmental sounds compared to conventional high-end digital amplification. Subjective comments from participants in this study also revealed that none of them objected to the non-linear frequency compression algorithm; instead, many reported better speech understanding (Wolfe, *et al.*, 2009:34). Further research on this topic found that the non-linear frequency compression processor improved speech sound detection thresholds and consonant as well as plural recognition scores for adults; vowel perception was not significantly changed (Glista *et al.*, 2009:642). It was also obvious that children were more likely to show preference for non-linear frequency compression processing than were adults. Variance in outcome results at the individual level was considerable as some individuals experienced greater or lesser benefit than the candidacy predictors would lead one to expect. Therefore, further research is needed to generalize predictions of candidacy for this technology (Glista *et al.*, 2009:642).

It is not yet clear whether there is a minimum limit to the degree of hearing impairment above which frequency compression is either not helpful or produces an unacceptable sound quality (McDermott, 2008:3). Extensive trials have demonstrated the benefits of using non-linear frequency compression in many adults and children with severe to profound hearing loss (McDermott, 2010:1). Similar benefits may also be obtained by users who have less severe losses, since current research suggests that even persons with mild hearing losses found that non-linear frequency compression can provide comfortable listening if the cut-off frequency is set relatively high (above 4 kHz) (McDermott, 2010:4). This is not surprising, because there is little or no harmonic pitch information present in most types of sound at the high frequencies that are affected by frequency compression with such settings. On the other hand, useful information is present in some high frequency sounds, particularly the fricative consonants of speech. It is certainly plausible that the perception of those sounds would be improved by limited application of frequency compression (McDermott, 2008:3). Even people with normal hearing would theoretically benefit from SoundRecover under certain listening conditions. In particular, when using a telephone, which has an upper frequency limit below 4 kHz, it can be difficult to understand unfamiliar words if they contain certain high frequency phonemes. For example, over the phone [s] is easily confused with [f], and in many instances is not audible at all. Under these conditions some frequency compression above a relatively high cut-off frequency could improve the listener’s ability to hear and to discriminate such speech sounds. Therefore, it is highly likely that non-linear frequency compression, when appropriately fitted, could benefit a high percentage of hearing aid users (McDermott, 2010:4). To what extent perceptual benefit can be obtained depends on both the technical function of the frequency-lowering scheme and on the way the variable parameters of the scheme are fitted to the hearing aid user (McDermott, 2010: 2).

Recently non-linear frequency compression has been evaluated on persons with mild hearing loss. Boretzki and Kegel (2009:6) found that the identification of the [s] sound have been shown to improve with the use of this algorithm. This suggests that understanding speech passages with low loudness predictability was improved, since the findings indicated initial improvements in speech recognition for high frequency weighted speech material. Also, detection thresholds for high frequency inputs were lower, which may have resulted in improved audibility of high-frequency consonants. Furthermore, test subjects subjectively perceived hearing with non-linear frequency compression as more comfortable than without it. These authors concluded that non-linear frequency compression should be considered as an option for subjects with mild to moderately-severe hearing loss (Boretzki & Kegel, 2009:6). Interesting however, a study done on the significant overall benefit from non-linear frequency compression, found that children were more likely to benefit from this algorithm than adults; also, participants with greater hearing loss confined more to the high frequencies were more likely to benefit (Glista *et al.*, 2009: par. 3; Glista *et al.*, 2009:642).

More recently it was found that non-linear frequency compression is a viable means to provide consistent audibility of sounds through to 8 kHz for children with a moderate hearing loss (Nyffeler, 2010:1). A group of children experienced significant improvements in audibility and recognition of high frequency speech sounds after only six weeks of use. Preliminary analysis also suggests that these children experienced improvements in their production of fricatives and affricates, and it appears that extended use of this algorithm may allow further improvement in speech recognition. Furthermore, none of the children objected to the use of non-linear frequency compression and although they were blinded to which setting they were using during the trials, nine out of fifteen children expressed a preference for this algorithm (Nyffeler, 2010:2).

Lastly, it was found that non-linear frequency compression resulted in more satisfaction and greater benefit for hearing aid users in both quiet and noisy environments and improved the speech recognition threshold of seven out of eleven subjects (Bohnert, Nyffeler & Keilmann, 2010:6). They also concluded that it seemed that participants with a more severe hearing loss in the high frequencies benefited more from this algorithm (Bohnert *et al.*, 2010:7). A visual representation of the working of the non-linear frequency compression algorithm is provided in Figure 3-3.

Figure 3-3: Visual representation of non-linear frequency compression (Phonak, 2009).

The use of non-linear frequency compression signal processing requires individualized fine tuning, in order to optimize the audibility of the frequency-lowered band (Scollie *et al.*, 2008:7). If sounds are lowered too much, speech may take on a lisping quality that may be noticeable and objectionable to the wearer. If sounds are not lowered enough, the end user may not derive any additional benefit over and above what the hearing aid provides without non-linear frequency compression processing (Scollie *et al.*, 2008:7). Therefore it is important that the audiologist or hearing aid acoustician is aware of the adjustable features that influence the strength of this algorithm and apply it according to each hearing aid user's preference.

3.6 HEARING HEALTH CARE IN THE SOUTH AFRICAN CONTEXT

Hearing health care services do not fall into the category of high profile or glamorous specialties but they do have the potential to improve the quality of life of the very large number of people with a hearing loss who would benefit from new technology (Davis, 2006:39), for example non-linear frequency compression technology.

Healthcare systems are changing the way people think about health and health care by placing considerable emphasis on promoting healthy lifestyle choices, early identification of health problems together with early support to overcome them, personalization of healthcare, quality assured, evidence-based intervention, and involvement of the general public in decisions about health care (Davis, 2006:40). Life-threatening conditions attract more public support and government action to reduce morbidity, mortality and chronic conditions, with a less visible disability such as a hearing loss being less of a priority. Hearing loss almost always develops gradually, is not life-threatening and, in the view of the general public, does not merit urgent intervention. Taking the above into account, it becomes obvious that music perception with hearing aids would be considered even less of a priority since it can easily be seen as a luxury and not as basic need. However, as mentioned before, music plays a central role in all human cultures, and for humans the experience of music is an important contribution to quality of life (Luis *et al.*, 2007:686). In order to maintain healthy individuals and healthy societies it therefore is important to address this matter.

The degree of unmet needs, the late age of presentation of most patients and the problems they have in adapting to hearing aids at an older age suggest that screening for hearing impairment in older people ought to be investigated as a priority (Davis, 2006:44). Hearing impairment in adults is a highly prevalent major public health problem that is often left too late before available services are accessed. There is a lack of capacity in audiological services (worldwide), especially with increasing numbers of people seeking help. Enabling audiologists to efficiently practise their profession is one of the keys to filling this capacity gap (Davis, 2006:41).

According to the World Health Organisation (1998) every individual has the right to optimal health care, including hearing health care, and it is the responsibility of the government to provide these services to all people. The South African government's policy with regard to health states that all South Africans have the right to essential and comprehensive health care services (White Paper for the Transformation of the Health System in South Africa, 1997). Although this policy exists in theory it is, due to several factors including limited resources and facilities, not possible to apply these principles in practice.

South Africa's health care system consists of a large public sector with a smaller private sector where health care varies from the most basic primary health care that is provided by the government to highly specialized services available in the private sector. The public sector serves around 80% of the population and is characterised by a shortage of basic equipment, medication, trained personnel as well as inadequate essential resources like water and electricity provision (National Department of Health, 2004). Furthermore, the diversity in language and culture in South Africa, as well as the growing awareness of recognition of this diversity, present a challenge to therapists regarding service delivery to persons with a hearing loss (Louw & Avenant, 2002:145). It is well-known that deafness has taken precedence over ethnicity in the deaf community and it has been erroneously assumed that deafness precludes ethnic and racial group membership. The following factors influencing service delivery in the South African context, especially in rural areas, can be highlighted (Louw & Avenant, 2002:146-147):

- The South African population is characterized as a multi-cultural society and shows great diversity in geography, language and culture. Currently, the majority of audiologists belong to a minority cultural group and cultural mismatches between professionals and the clients they serve exist, which is further compounded by language barriers.

- The family structure in many families tends to be extended, rather than nuclear and may also be multi-generational – specifically in the context of high HIV/AIDS infection rates in South Africa. This often implies that hearing health care is not the main priority in the family.
- Families differ in their perception of disabilities and a characteristic of African families is often their fatalistic attitude towards disability which leads to an accepting, passive attitude to hearing problems and may negatively impact on their seeking intervention services for family members with a hearing loss.
- Due to limited schooling and limited access to printed information, many persons from low-income families are disoriented and confused regarding their expectation in terms of normal hearing and hearing health services.
- Health beliefs and practices may further play a role in families seeking intervention. Traditional healers may form an integral part of a family's approach to illness and health. Technology and Western medical practices may be viewed as an intrusion on accepted and respected traditional activities and rituals. Families may be reluctant to make use of professional services and devices such as hearing aids.
- The African emphasis on community may also impact on the provision of intervention services to persons with a hearing loss. In African cultures co-operation, interdependence and the well-being of the group are rated higher than the individual.
- Another African concept, namely that of time, needs to be taken into account in the planning of provision of intervention services. In Western models, future planning and independent communication are fundamental to the process. However, in traditional African culture time is a two dimensional phenomenon, with a long history, a present and virtually no future. Future events are viewed as 'no time' and have no place in the concept of time since the future is unknown and can not be understood.

Other aspects that influence service delivery in the South African context are the high costs involved in hearing health care, poverty, insufficient supported government services as well as negative attitudes and ignorance of health care workers (Loening-Voysey, 2002:105). In South

Africa many people do not receive health care services since treatment of hearing disorders may lead to discrimination in the community.

From the above it is evident that hearing health care service delivery in South Africa is challenging and that these factors have to be addressed in an innovative way to provide culturally congruent and sensitive hearing health care services to South Africans.

3.7 CONCLUSION

Frequency lowering hearing aids have produced mixed results, with some studies showing substantial improvement and others showing no improvement or even degradation in performance (Stelmachowicz, Pittman, Hoover, Lewis & Moeller, 2004:561). However, the signal processing schemes across studies have differed substantially in concept and implementation. Other differences across studies were likely influenced by the nature of the frequency lowering algorithm, materials used for assessment as well as the severity and type of audiometric configuration of the participants (Gifford *et al.*, 2007:1195). In addition, some studies included subjects who clearly were not candidates for this type of technology (Stelmachowicz *et al.*, 2004:561).

Early efforts to exploit frequency lowering schemes encountered two serious problems (Jerger, 2009:288): First, it became evident early on that the hearing aid user would have to learn new acoustic precepts. Second, because of limitations in early analog technology, disturbing conversion artefacts could not be easily removed from the mixture of the original and the transposed signals in transposition algorithms. Modern digital signal processing has however substantially changed the playing field, renewing interest in frequency lowering strategies (Jerger, 2009:288).

Although frequency lowering strategies like non-linear frequency compression holds certain challenges for the hearing aid user, research has demonstrated that adult listeners can rather quickly learn to make use of high frequency information shifted to lower frequencies (Munro, 2007:14). One should keep in mind that the processed sounds were never heard by hearing aid users before and as such it is unrealistic to expect listeners to identify the new sounds without adequate training and experience (Kuk *et al.*, 2006: par.8).

The case studies referred to above underline the need for hearing care professionals to carefully consider all available options when treating high frequency hearing loss. The results of these cases support changing conventional amplification to amplification with frequency lowering technology (Davis, 2001: par. 20; Boothroyd & Medwetsky, 1992:156).

3.8 SUMMARY

This chapter provides an in depth discussion of the current available literature on frequency transposition and frequency compression hearing aids. Non-linear frequency compression technology, a feature of the hearing aids used in this study as data collection apparatus, is also described in detail.

Every person is immersed in an environment filled with sound, and being able to understand speech is not the only function of hearing. For most people, listening to music is also a significant and enjoyable experience. Therefore, it is not surprising that people with a hearing aid frequently express a wish to be able to enjoy listening to music with their device (McDermott, 2005:65). With the theoretical background described in Chapters 1-3, this study aims to address the need for musical enjoyment of non-linear frequency compression hearing aid users by following the procedures set out in Chapter 4.

Chapter 4

METHOD

Chapter aim: The aim of this chapter is to provide an outline of the methodological approach implemented in the conduction of the empirical research component of this study.

4.1 INTRODUCTION

Research is the systematic process of collecting and logically analyzing data in order to answer specific questions or solve specific problems (McMillan & Schumacher, 2006:9). An important aspect of the research process is the method employed to conduct the research, since the researcher must ensure that the acquired information is reliable and valid (McMillan & Schumacher, 2006:9).

The professional knowledge underlying an occupation is mainly scientific information that consists in part of generalizations made from the everyday practices and observations in that occupation (De Vos, Schulze & Patel, 2005:24). Until such generalizations are systemized and found to be valid they can, however, not qualify as scientific knowledge. The main task of professionals in an occupation involving service delivery to people is therefore to transform these generalizations through the process of research to scientific proposals. According to De Vos *et al.*, (2005:25) professional research is a scientific phenomenon directed towards addressing problems that arise from service delivery to people. The assumption is therefore made that professional research within an occupation, like that of the audiologist, will not only lead to the expansion of knowledge within the field but will also result in better service delivery to persons with a hearing loss. It should be clear from the above that it is of critical importance to apply the correct procedures and methods in the research process in order to increase the reliability and validity of obtained results.

The research question underlying the current research project was already highlighted in Chapters 1, 2 and 3. Advances in modern digital hearing aid technology focus almost entirely on improving the intelligibility of speech in noisy environments. The effects of hearing aid processing on music signals and on the perception of music, however, received very little attention, despite reports that hearing impairments are the primary impediment to enjoyment of music in older listeners, and that hearing aid processing is frequently so damaging to music signals that hearing aid wearers often prefer to remove their hearing aids when listening to music (Wessel *et al.*, 2007:1).

These are early days for most forms of frequency lowering hearing aids, with non-linear frequency compression certainly no exception (Scollie *et al.*, 2008:7). As Ross (2000: par. 10) indicated, there is very little research evidence attesting the effectiveness of frequency compression, with the available research focuses mainly on speech perception. The results of the current study may therefore provide audiologists with valuable scientific information on the advantages and disadvantages of non-linear frequency compression with musical stimuli, thereby addressing an area of limited knowledge in the field of Audiology as it currently stands. Determining the influence of non-linear frequency compression on music perception may assist in more evidence-based hearing aid fittings to improve the quality of life for persons with a hearing loss; it may also assist in counselling these persons regarding their expectations of hearing aids. Evidence-based practice has been widely embraced in many health care fields as a way of maintaining currency of knowledge and state-of-the-art treatment recommendations in an age of abundant information and rapid scientific progress (Cox, 2005:419).

Despite evident advances in hearing aid technology, the percentage of people with hearing loss owning hearing aids (about 22%) has not changed since 1991 (Cox, 2005: 420). A question arises as to why better hearing aids have not produced a corresponding improvement in satisfaction with amplification. The answer lies, at least in part, in the fact that the scientific basis of hearing aid fitting has fallen far behind the technological development of amplification devices (Cox, 2004:10). This problem has two components: Firstly, there is relatively little high-quality research to provide effective guidelines for the fitting process. Secondly, practitioners are generally unprepared to critically evaluate the body of research that does exist (Cox, 2005:420).

As a result of these factors, professionals involved in providing hearing health care do not have an accurate appreciation of the value of technological developments in amplification or other newly proposed treatment strategies for hearing aid wearers (Cox, 2005: 420). Therefore, this study hopes to contribute to the provision of effective hearing health care to music loving hearing aid users and thereby to the attainment of a new level of success in the profession of Audiology.

Taking the above into account, the purpose of this chapter is to describe the research method that was used to determine the influence of non-linear frequency compression on the perception of music of adults with a moderate to severe hearing loss. The description of the research method will focus on the aims formulated for the study, the research design implemented, ethical considerations taken into account, participants included, material and apparatus used for data collection as well as procedures implemented for the collection, recording and analysis of data. The chapter will conclude with a general summary.

4.2 AIMS

The following aims have been formulated for this study:

4.2.1 Main aim

The purpose of this study was to determine, through the use of a music perception test compiled by the researcher, the influence of non-linear frequency compression on the perception of music by adults presenting with a moderate to severe hearing loss.

4.2.2 Sub-aims

The following sub-aims were formulated in order to attain the main aim of the study:

- ♬ To compile a test for music perception as part of the material for data collection;
- ♬ To determine the influence of non-linear frequency compression on the perception of:
    - rhythm;

- timbre;
- pitch;
- melody;

♬ To determine the influence of non-linear frequency compression on participants' subjective impression of listening to music;

♬ To determine whether there is an objective and subjective benefit for listening to music with the extended use of non-linear frequency compression.

4.3 RESEARCH DESIGN

The purpose of a research design is to plan and structure the research project to provide results that are judged to be credible (McMillan & Schumacher, 2006:117). The purpose of social research may be three-fold, namely, that of *exploration, description* and *explanation* (Babbie, 2002:79). Due to the empirical nature of the study, research was conducted within a *quantitative* paradigm (with a combination of quasi-experimental and non-experimental research designs) and was distinguished from a qualitative approach by its purpose, process, data collection procedures, data analysis and reported findings (Leedy & Ormrod, 2005:102-103).

The purpose of the study was to *explore* the topic of the effect of non-linear frequency compression on the music perception abilities of adults in an attempt to provide a basic understanding of this phenomenon; a need exists for exploration in this field due to the dearth of reported research on non-linear frequency compression technology. This goal was met by *determining* and *describing* the music perception abilities in a number of participants and also by attempting to *explain* the causality between non-linear frequency compression and music perception. The field of quantitative research is more formalized, explicitly controlled and is more precisely defined (Neuman, 2006:253); such research designs maximize objectivity by using numbers, statistics, structure and control (McMillan & Schumacher, 2006:23). Procedures for data gathering and measurements are compiled prior to the study and are conducted in a standardized manner (Leedy & Ormrod, 2005:102). Data collection from a quantitative approach is specifically related to these variables, and is collected from a sample of a specific population. In the case of the current study, data collection took place in four phases. A schematic representation of the research design used in each phase is presented in Figure 4-1 below, whilst a detailed schematic representation of the alternating assessment schedule used in Phase 2 and Phase 3 is contained in Table 4-11.

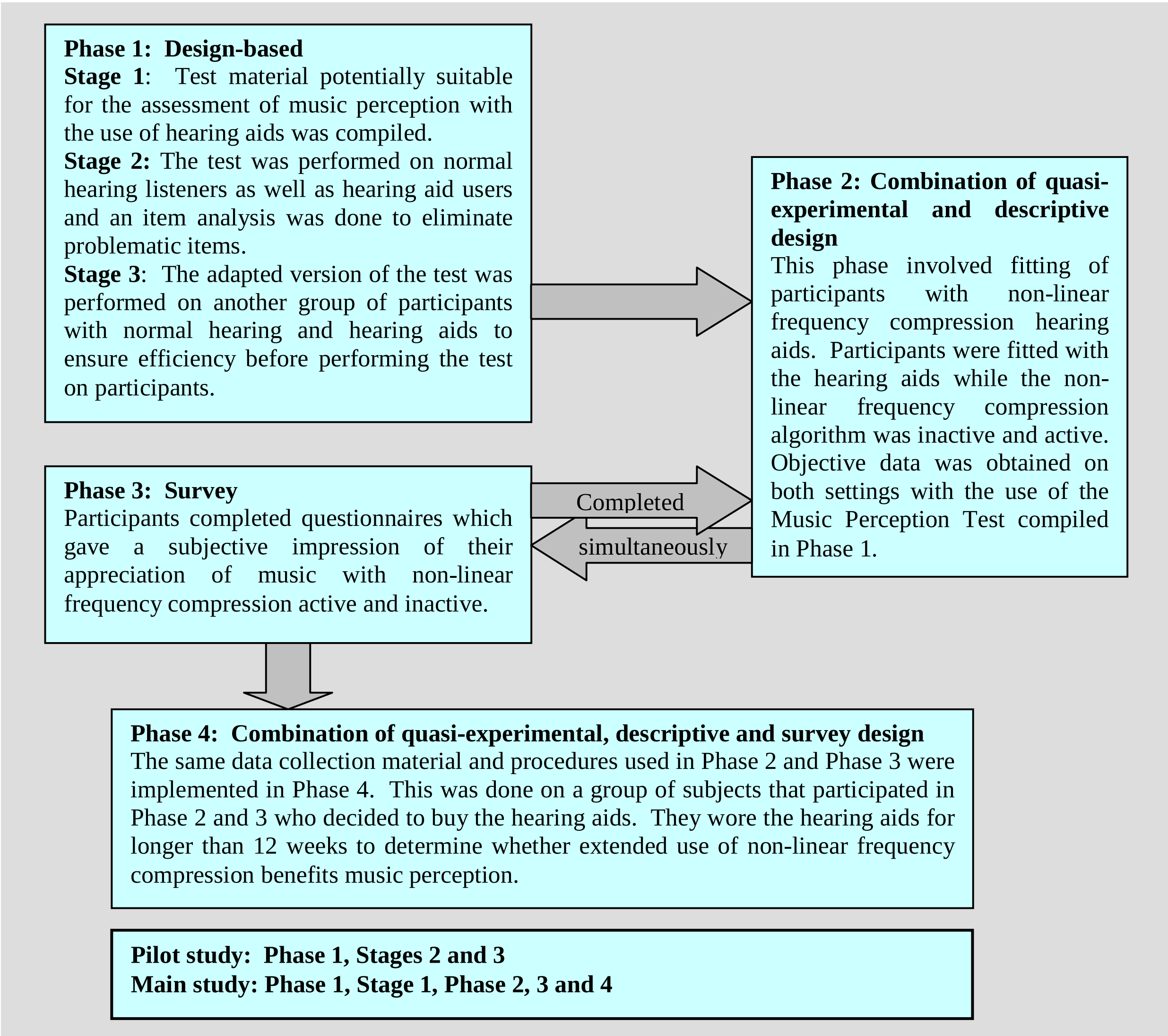


Figure 4-1: Schematic representation of the research phases of the current study

Phase 1 entailed the compilation of the Music Perception Test (MPT) and can be described as design-based. Although this paradigm is mostly applied to educational contexts (Barab & Squire, 2004:5), it provides a suitable framework for the first phase of this study, involving the design of a test for the assessment of music perception in hearing aid users. In the conventional application of this method, theoretical expertise is used to design a particular learning environment or intervention, which is then applied in an educational setting (Barab & Squire, 2004:3). The principles of this approach was applied to the **first stage** of this phase of the current study by using theoretical knowledge and literature to compile test material that would be potentially suitable for the assessment of music perception with hearing aids within the South African context. **Stage 2** involved the presentation of the MPT to normal hearing listeners and hearing aid users. Based on the findings of Stage 2, an item analysis was performed to eliminate or change stimuli that resulted in high error rates. In **Stage 3** the adapted version of the test was performed on a different group of normal hearing listeners and hearing aid users. This stage in the research process served as the pilot study and was conducted to ensure the appropriateness and efficiency of the test material in order to render optimal validity and reliability of the results of the main study.

A quasi-experimental research design was selected to form the structure of the method employed in **Phase 2**. This phase involved the fitting of participants with non-linear frequency compression hearing aids. Objective data was obtained with the hearing aids on conventional settings (non-linear frequency compression algorithm inactive) and with the non-linear frequency compression algorithm activated. Advantages of experimentation included the control over the experiment and the opportunity to observe change over time (Babbie, 2002:219). A true experiment starts with a hypothesis, modifies a situation, and then compares the outcome with or without modification (Neuman, 2006:247) as was done in the current study where the hypothesis was made that non-linear frequency compression might influence music perception. This was verified with the activation and deactivation of the non-linear frequency compression algorithm to compare the possible music perception benefits received by hearing aid users. Random assignments of subjects are also necessary for creating similar groups in order to facilitate comparison (McMillan & Schumacher, 2006:47) and therefore a cross design was used in this phase. This implies that some participants were first fitted with the non-linear frequency compression algorithm active, while for others this algorithm were first inactive, as calculated with the use of statistical programming. Some deviations from the classical experimental design were made in order to materialize the aims of research due to the characteristics of this study. A quasi-experimental design still allowed for testing of causal relationships in a variety of situations (Neuman, 2006:256), but accounted for the lack of randomness in the selection of participant group members in the current study, since only a limited number of adults fitted the selection criteria (Leedy & Ormrod, 2005:237). Furthermore, in this phase single blinding was used. This implies that only one party knows which group a subject was assigned to (Cox, 2005:428). During the course of the evaluation, the participant did not know whether the frequency compression algorithm was activated or not. This removed any potential participant bias that could influence the results (Bentler & Duve, 2000:636).

Within the framework of non-experimental research this study had a descriptive as well as a survey design. A descriptive design provides a summary of an existing phenomenon by using numbers to characterize individuals or a group (McMillan & Schumacher, 2006:24). It assesses the nature of existing conditions and is limited to characterizing something as it is (McMillan & Schumacher, 2006:24). In the current study, the manner in which participants perceived music with and without the use of non-linear frequency compression was described.

In the survey research design the investigator administered questionnaires in order to collect data and to describe attitudes, beliefs and opinions (McMillan & Schumacher, 2006:25). **Phase 3** of this study involved two short, structured questionnaires to be completed by the participants. The first questionnaire obtained background information from participants while the second questionnaire elicited a subjective impression of the participants' musical experiences with the hearing aids when the non-linear frequency compression algorithm was both active and inactive. After completion of the questionnaire participants' perception of music with non-linear frequency compression active and inactive were compared in order to determine possible advantages of this algorithm for listening to music.

In **Phase 4** the same music perception test was performed on a group of participants that used the non-linear frequency compression algorithm for at least twelve weeks. They were also asked to again complete the second questionnaire. This was done in order to explain the effect of extended use of non-linear frequency compression and acclimatization on music perception.

In most descriptive research and some survey research, there in only one variable of interest (McMillan & Schumacher, 2006:55) and specific variables are not necessarily isolated and manipulated. The variable that is manipulated by the researcher to investigate the effect is called the independent variable while the dependent variable is the one which is affected by the independent variable (McMillan & Schumacher, 2006:54). In this study the independent variable was non-linear frequency compression with music perception (of the participants) as the dependent variable. Control variables are defined as factors that can be controlled by the researcher to neutralize or eliminate any influence which they might have on the phenomenon being researched (Bless & Higson-Smith, 2000:69) and in the current study included the adult population as well as the degree of hearing loss.

As can be seen from the above, an extended research design was implemented to accommodate the different phases of the study. This included the design of data acquisition material as well as a combination of quasi-experimental, descriptive and surveys designs.

4.4 ETHICAL ASPECTS REGARDING RESEARCH

It is important that any research be conducted within the framework of research ethics. Therefore, ethical clearance for this study was obtained from the institutions involved. The underlying foundation of ethical research is to preserve and protect the human dignity and rights of all the participants participating in a research study (Jenkins, Price & Straker, 2003:46). The ethical principles of autonomy, beneficence and justice were incorporated in this study, and are discussed below:

- **<u>Autonomy</u>**

In research, autonomy means strictly voluntary participation in any research project (Leedy & Ormrod, 2005:107) and includes the following components:

Table 4-1: The components of autonomy relevant to this study

COMPONENT	DESCRIPTION
Informed consent	The participants involved in a study should have the legal capacity to give consent (Jenkins *et al*., 2003:47), by making an informed decision whether or not to take part in this study. Written informed consent was obtained from each participant through a letter (Appendix A) explaining the purpose of the study, the procedures to be followed and the possible advantages and disadvantages of taking part in the study (Struwig & Stead, 2001:68). It also stated that information will be kept strictly confidential. By signing the letter, participants acknowledged that they were informed about the purpose and procedures of the study and that participation is completely voluntary.
Withdrawal of participants	The norm for social research is that all participation in research should be voluntary (Babbie, 2002:521). The participant therefore reserves the right to withdraw at any time from the study, without being penalized or sacrificing any tangible benefits they might receive for participating in this study.
Privacy, confidentiality and anonymity	The participants' right to privacy was protected by viewing all information to be confidential and anonymous (Strydom, 2005:69).
Disclosure of information	Participants were informed that the information gained from the study might be used for academic purposes – either as an article or presentation. This will be done in an objective manner, keeping the principle of confidentiality and the language accurate, objective and unambiguous. All forms of bias and plagiarism were avoided during the report writing. Errors and limitations of the study were admitted and recommendations were made for future research (Strydom, 2005:57).
Ethical clearance	Ethical clearance for this study was requested from the Postgraduate Research and Ethics Committee of the Faculty Humanities, University of Pretoria (Appendix B). A letter requesting permission for conduction of the study at the audiological practice was sent to the directors of the practice (Appendix C) and permission was obtained from the audiological practice (Appendix D).

As can be seen from Table 4-1 all the principles of autonomy were observed in the current study.

- **Beneficence**

Beneficence refers to showing active kindness and to the conferral of benefits (Hyde, 2004:297). Participants should not be exposed to undue physical or psychological harm (Babbie, 2002:522). This was ensured by including the components discussed in Table 4-2:

Table 4-2: Beneficence as a relevant ethical principle for this study

COMPONENT	DESCRIPTION
Competency	The researcher is qualified to conduct research due to her qualifications and experience in the field of Audiology. Three research supervisors from the University of Pretoria supervised the study, and valuable input was also gained from leaders in the local and international field of Audiology. The researcher (STA 0026395) and the supervisors are registered with the Health Professions Council of South Africa (HPCSA).
Relevance	As all clinicians are urged to conduct evidence-based practice, this study is highly relevant and may yield valuable information regarding the prescription of technology to meet the needs of the population with a hearing loss.
Risks	Taking part in a research study may involve the disruption of regular, daily activities (Babbie, 2002:521). However, the risk of participating in this study did not unreasonably exceed the normal risk of day-to-day living. No medical risks were involved in this study. Normal procedures for any hearing aid fitting were followed. A date and time were arranged with each participant to suit him/her.
Discrimination	Participants were not discriminated against on grounds of gender, race or economic status.

By applying the principles of beneficence, as described in Table 4-2, the researcher ensured that no harm was done to any of the participants in the current study.

- **Justice**

Justice refers to honesty with professional colleagues (Leedy & Ormrod, 2005:108). The researcher had a responsibility towards other colleagues in the scientific community and therefore all co-workers were acknowledged. Behaviour throughout the research process was strictly professional and the collection of data took place in an honest and responsible manner. The researcher also has an ethical responsibility to convey the results of this study accurately. The true results obtained had at all times been indicated as the results of this study in order to avoid research misconduct (Maxwell & Satake, 2006:67; Ingham, 2003:325).

4.5 PARTICIPANTS

For this study adult clients of a private hearing aid practice were used. Data collection was conducted by means of real-ear measurements, performance in the MPT as well as hand-delivered, personal questionnaires on the premises. As Phase 1 of the study constitutes the pilot study, participants included in Phase 1 are described in detail in section 4.7.1.1. The main study involved Phase 2 and Phase 3, which included a total of 40 participants as described below.

4.5.1 Sampling techniques and sample size

Due to the quasi-experimental design of the study where random assignment of subjects was not possible, true quantitative sampling techniques were not used. Non-probability sampling techniques are usually associated with qualitative research designs, since the characteristics of each case determine whether it is selected or not (Neuman, 2006:220). The researcher used a non-probability sampling technique which does not include any type of random selection from a population, but rather participants who happen to be accessible or who may represent certain types of characteristics (McMillan & Schumacher, 2006:125). This method is justified on grounds of feasibility (Babbie, 2005:189). The specific type of non-probability sampling used was the purposive convenient sampling method. According to this method participants were chosen on the basis of accessibility and because they articulated with the researcher's aim of study (McMillan & Schumacher, 2006:125). This method seemed appropriate for the current study because participants' characteristics articulated with the aims of the study. Furthermore, participants were accessible as clients of the hearing aid practice selected, thereby addressing the logistic convenience of the researcher. This method was also time effective.

4.5.2 Selection criteria

The following selection criteria were developed for all participants with hearing aids:

Table 4-3: Selection criteria

CRITERIA	JUSTIFICATION
Geographical location Participants had to reside within the Gauteng province.	Data collection took place at a private practice in Pretoria as it was logistically convenient for the researcher. The practice is also within an hour's reach for most people staying in the Gauteng area. As the data collection took place in more than one phase, participants had to visit the practice more than once.
Language status Participants had to be proficient and literate in English.	This is a language in which the researcher is proficient and therefore the MPT, questionnaires, all instructions and explanations were provided in English. Furthermore, the 2001 South African Census indicate that English is the third most common primary language, the most common second language in Gauteng (Statistics South Africa, 2001) and the most commonly used language in South Africa (Napier & Napier, 2002:9).

CRITERIA	JUSTIFICATION
Age Participants had to be between the ages of 18 years 0 months and 64 years 11 months.	Persons of 18 years and older have matured central auditory systems since the maturation of the central auditory nerve system is completed at the age of approximately twelve years (Bellis, 1996:71). According to Katz and Wilde (1994:492) the performance on central auditory processing tests is consistent from the teenage years until the middle of adulthood and only starts to deteriorate from the age of 65 years and older due to physiological changes in the brain. This age group (18-65 years) is further legally independent and permission to participate in this study can be obtained directly from the participant. Older adults are described as persons 65 years and older (Weinstein, 2002:597).
Middle ear functioning Participants were required to present with normal middle ear functioning.	Middle ear pathology could result in adding a conductive component to the hearing loss (Rappaport & Provencal, 2002:19). People with a conductive or mixed hearing loss experience different amplification needs than people with sensory neural hearing loss (Dillon, 2000:256).
Onset of hearing loss All participants had to have an acquired hearing loss rather than a congenital hearing loss.	DSL v5.0 targets for adults were used as fitting formula during the fitting of the prototype hearing aids. Adult targets for DSL are on average 7 dB lower than those for children and will make a difference in the fitting because the amount of gain will differ with different targets (Scollie, Seewald, Cornelisse, Moodie, Bagatto, Laurnagaray, Beaulec & Pumford, 2005:166). If adults with a congenital hearing loss were included, they would probably (even though they are now adults) be using DSL child targets as this is what they were fitted with before and are used to.
Configuration and degree of hearing loss Participants had to have a bilateral, moderate to severe sensory neural hearing loss, with a pure tone average of 41-90 dB at the frequencies 500 Hz, 1kHz and 2kHz (Plante & Beeson, 1999:100; Mueller & Hall, 1998:951).	The hearing aid with the non-linear frequency compression algorithm was specifically designed for people with severe hearing losses (Glista & McDermott, 2008:5) and therefore this type of hearing loss will be a good indicator for a person to benefit from non-linear frequency compression.
Previous experience with hearing instruments Participants should not have had non-linear frequency compression hearing aids before. Participants' current hearing aids had to be digital hearing aids as opposed to analogue hearing aids.	Previous experience with non-linear frequency compression technology will possibly have influenced the participant's beliefs and attitudes towards frequency lowering technology and therefore can cause the participant not to be objective in the study whereas with current use of analogue hearing aids one might measure the switch from analogue to digital and not the effects of non-linear frequency compression (Flynn, Davis & Pogash, 2004:480). The hearing aids used in this study were digital hearing aids and if participants were already used to digital amplification, it might reduce adaptation problems and time to adjust to the new hearing aids.
Current hearing aid experience Participants had to have at least two years' experience with conventional amplification hearing aids utilizing serial or parallel processing set according to the amplification targets described by DSL v5.0 (Scollie, 2006:10).	The person's current hearing aids must be optimized to reflect current best practice (Flynn *et al.*, 2004:480) to enable accurate comparisons between different technologies. A minimum of two years' experience with conventional amplification hearing aids is required because previous hearing aid experience will also influence acclimatization to non-linear frequency compression hearing aids and a homogeneous acclimatization period will ease comparison of results between patients.
Voluntary informed participation Participants had to take an informed decision to participate voluntarily in this study.	Persons taking part in any research project should do so of their own choice, based on comprehensive information provided in advance (Struwig & Stead, 2001:67).

The clients of the selected hearing aid practice met the above-mentioned selection criteria.

4.5.3 Selection procedure

The following procedures were followed during the selection of participants:

- Written permission to conduct this research project was provided by the directors of the Audiology practice. Ethical clearance was granted by the Postgraduate Research and Ethics Committee, Faculty of Humanities, the University of Pretoria.
- The selection criteria for identification of possible candidates were submitted to the Audiology practice; subsequently the researcher consulted with an audiologist from the practice to compile a list of possible participants and to obtain their contact details.
- The researcher contacted all the candidates either telephonically or by e-mail. In this process the aim and the procedures of the study were explained. If a potential candidate agreed to take part in this research project an appointment was made for a date and time that suited both the candidate and the researcher.
- If the candidate declined the offer to take part in this research project, he/she was thanked for his/her time.
- These procedures were followed until the appropriate number of candidates for all the different phases of the study agreed to participate in the research project.

4.5.4 Description of participants

Table 4-4 presents the biographical information of the persons that participated in the main study (Phase 2 and Phase 3). The data in this table was obtained from the participants' files at the Audiology practice.

Table 4-4: Biographic information of participants with hearing aids included in Phase 2 and Phase 3 of the study.

Partici-pant	Age	Cause of hearing loss	Shape of hearing loss	Pure tone average (PTA)	Oto:acoustic emissions (OAE's)	Current hearing aids	Signal processing scheme	Time wearing hearing aids
1	62 years	Unknown	R: Sloping L : Sloping	R: 77 dB L: 85 dB	Absent for both ears.	R: Una SP AZ L: Una SP AZ	dWDRC	3 years
2	64 years	Unknown	R: Sloping L: Sloping	R: 60 dB L: 60 dB	Absent for both ears.	R: Extra 411 L: Extra 411	dSC	4 years
3	64 years	Unknown	R: Flat L: Flat	R: 75 dB L: 63 dB	Absent for both ears.	R: Extra 311 L: Extra 211	dSC	3 years
4	51 years	Unknown	R: Flat L: Flat	R: 72 dB L: 88 dB	Absent for both ears.	R: Eleva 33 L: Eleva 33	dSC	3 years
5	33 years	Unknown	R: Sloping L: Sloping	R: 78 dB L: 62 dB	Absent for both ears.	R: Supero 411 L: Supero 411	dWDRC	15 years
6	44 years	Unknown	R: Sloping L: Sloping	R: 60 dB L: 60 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Eleva 22 L: Eleva 22	dWDRC	5 years
7	42 years	Unknown	R: Flat L: Flat	R: 63 dB L: 62 dB	Absent for both ears.	R: Una M AZ L: Una M AZ	dWDRC	3 years
8	59 years	Presbycusis	R: Sloping L: Sloping	R: 60 dB L: 60 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Extra 33 L: Extra 33	dSC	3 years
9	31 years	Unknown	R: Sloping L: Sloping	R: 75 dB L: 68 dB	Absent for both ears.	R: Una SP L: Una SP	dWDRC	2 years
10	63 years	Presbycusis	R: Sloping L: Sloping	R: 58 dB L: 57 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Eleva 311 L: Eleva 311	dWDRC	17 years
11	60 years	Unknown	R: Sloping L: Sloping	R: 63 dB L: 67 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Eleva 411 L: Eleva 411	dWDRC	3 years
12	21 years	Unknown	R: Sloping L: Sloping	R: 75 dB L: 68 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Extra 411 L: Extra 411	dSC	4 years
13	18 years	Virus infection	R: Sloping L: Sloping	R: 88 dB L: 88 dB	Absent for both ears.	R: Maxx 411 L: Maxx 411	dWDRC	12 years
14	26 years	Unknown	R: Sloping L: Sloping	R: 60 dB L: 55 dB	Absent for both ears.	R: Extra 311 L: Extra 311	dWDRC	14 years
15	39 years	Unknown syndrome	R: Sloping L: Sloping	R: 72 dB L: 72 dB	Absent for both ears.	R: Solo prog L: Solo prog	dWDRC	19 years
16	58 years	Presbycusis	R: Sloping L: Sloping	R: 57 dB L: 63 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Extra 311 L: Extra 411	dSC	4 years

17	61 years	Unknown	R: Flat L: Flat	R: 80 dB L: 88 dB	Absent for both ears.	R: Novoforte E4 L: Novoforte E4	dWDRC	7 years
18	43 years	Unknown	R: Sloping L: Sloping	R: 50 dB L: 63 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Una M L: Una M	dWDRC	2 years
19	38 years	Trauma	R: Flat L: Flat	R:53 dB L:52 dB	Absent for both ears.	R: Solo prog L: Solo prog	dWDRC	7 years
20	64 years	Presbycusis	R: Sloping L: Sloping	R: 65 dB L: 78 dB	Absent for both ears.	R: Extra 311 L: Extra 311	dWDRC	3 years
21	60 years	Presbycusis	R: Sloping L: Sloping	R: 43 dB L: 52 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Una M AZ L: Una M AZ	dWDRC	7 years
22	42 years	Unknown	R: Sloping L: Sloping	R: 58 dB L: 45 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Una M AZ L: Una M AZ	dWDRC	2 years
23	61 years	Unknown	R: Flat L: Sloping	R: 85 dB L: 48 dB	Absent for both ears.	R: Astro L: Astro	dWDRC	15 years
24	58 years	Unknown	R: Flat L: Flat	R: 63 dB L: 62 dB	Absent for both ears.	R & L: Oticon digital (type unknown)	Unknown	8 years
25	64 years	Presbycusis	R: Sloping L: Sloping	R: 58 dB L: 57 dB	Absent for both ears.	R: Solo prog L: Solo prog	dWDRC	2 years
26	64 years	Presbycusis	R: Sloping L: Sloping	R: 55 dB L: 55 dB	Absent for both ears.	R: Eleva 211 L: Eleva 211	dWDRC	4 years
27	61 years	Unknown	R: Sloping L: Sloping	R: 57 dB L: 85 dB	Lowered at low frequencies and absent at high frequencies for right ear. Absent for left ear.	R: Eleva 311 L: Eleva 311	dSC	10 years
28	64 years	Unknown	R: Sloping L: Sloping	R: 60 dB L: 48 dB	Absent for right ear. Lowered at low frequencies and absent at high frequencies for left ear.	R: Extra 311 L: Extra 211	dWDRC	5 years
29	60 years	Unknown	R: Flat L: Flat	R: 57 dB L: 57 dB	Absent for both ears.	R: Extra 311 L: Extra 311	dWDRC	5 years
30	60 years	Presbycusis	R: Sloping L: Sloping	R: 73 dB L: 73 dB	Absent for both ears.	R: Eleva 411 L: Eleva 411	dSC	12 years
31	64 years	Unknown	R: Flat L: Sloping	R: 78 dB L: 60 dB	Absent for both ears.	R: Extra 411 L: Extra 411	dWDRC	8 years
32	22 years	Virus infection	R: Flat L: Flat	R: 88 dB L: 85 dB	Absent for both ears.	R: Supero 411 L: Supero 411	dLim	17 years
33	62 years	Unknown	R: Sloping L: Sloping	R: 67 dB L: 83 dB	Absent for both ears.	R: Savia 311 L: Savia 411	dWDRC	6 years
34	47 years	Unknown	R: Flat L: Flat	R: 63 dB L: 63 dB	Absent for both ears.	R: Certena P L: Certena P	dWDRC	10 years

35	63 years	Presbycusis	R: Sloping L: Sloping	R: 65 dB L: 68 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Eleva 311 L: Eleva 311	dWDRC	3 years
36	64 years	Presbycusis	R: Sloping L: Sloping	R: 60 dB L: 53 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Certena P L: Certena P	dWDRC	6 years
37	58 years	Trauma	R: Flat L: Flat	R: 58 dB L: 68 dB	Absent for both ears.	R: Extra 311 L: Extra 311	dSC	4 years
38	60 years	Unknown	R: Sloping L: Sloping	R: 62 dB L: 72 dB	Absent for both ears.	R: Eleva 311 L: Eleva 311	dSC	7 years
39	31 years	Unknown	R: Sloping L: Sloping	R: 63 dB L: 63 dB	Absent for both ears.	R: Solo prog L: Solo prog	dWDRC	12 years
40	63 years	Noise-induced	R: Sloping L: Sloping	R: 63 dB L: 57 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Maxx 311 L: Maxx 311	dWDRC	6 years

The average age for hearing aid users in Phase 2 and Phase 3 was 57.7 years (ranging from 18 years to 64 years). All of them had a post-lingual onset of hearing loss and in most cases the cause of the hearing loss was unknown. In cases where participants were familiar with the etiology of their hearing loss, it was mostly contributed to presbycusis. Virus infections, trauma and exposure to excessive noise were also indicated as the cause of hearing loss in limited cases. The majority of participants (n=28) had a hearing loss with a sloping configuration[13] while other participants' (n=10) hearing loss were characterized by a flat configuration[14]. For two participants, the hearing loss in one ear had a sloping configuration while the hearing loss in the other ear was characterized by a flat configuration. Participants included in the study all had a moderate to severe hearing loss which can be described in more detail as:

- Moderate (pure-tone average of 41 dB to 55 dB)
- Moderately severe (pure-tone average of 56 dB to 70 dB)
- Severe (pure-tone average of 71 dB to 90 dB)

With the above clarification taken into account, one can conclude that of the 40 subjects (80 ears) that participated in the study, 11 ears had a moderate hearing loss, 45 ears had a moderately severe hearing loss and 24 ears had a severe hearing loss.

4.6 MATERIAL AND APPARATUS FOR THE COLLECTION OF DATA

The material and apparatus described below were utilized for the acquisition of data in this study. The same material and apparatus were used in all the phases of the study.

4.6.1 Material

The assessment material used in the current study for obtaining data included the MPT and questionnaires compiled by the researcher. For an assessment to be meaningful and useful, it

[13] Shows progressively greater hearing loss for higher test frequencies (Mueller & Hall, 1998:959)
[14] Hearing loss which neither increases nor decreases in relation to frequency (Mueller & Hall, 1998:925)

must have foundational integrity which may be assured if the assessment and assessment material adheres to the following principles (Shipley & McAfee, 2008:4):

- A good assessment is thorough: In order to accomplish thoroughness, the MPT and questionnaires were designed to elicit as much relevant information as possible to enable the researcher to obtain accurate and appropriate information.
- A good assessment uses a variety of assessment modalities: The data-acquisition phases of the current study included a combination of formal and informal testing by means of the MPT and questionnaires. This enabled the researcher to obtain both objective and subjective information on how participants perceive music.
- A good assessment is valid and reliable: Several measures were taken to ensure the validity and reliability of the MPT and questionnaires. These measures are described in detail in the sections to follow.
- A good assessment is tailored to the individual client. The MPT and questionnaires were compiled to be appropriate for the participants' age, skill level and ethno-cultural background.

4.6.1.1 Music Perception Test

Music involves a complexity of rhythm, melody, harmony, and dynamics (Galvin *et al.*, 2007:316). The choice of measures to access musical skills is limited because most music tests are designed to examine the skills of individuals undergoing formal music training (Don *et al.*, 1999:158). There are very few studies focusing on the perception of music through hearing aids (Looi *et al.*, 2008b:421) as most studies (Gfeller *et al.*, 2005; Kong *et al.*, 2005; Gfeller *et al.*, 1997; Gfeller & Lansing, 1991) and study material for the evaluation of music perception in persons with a hearing loss focus on cochlear implantees. Therefore, due to the shortage of available material to reach the aims of this study, the design of a music perception test was necessary. The MPT was compiled in conjunction with sound engineers and musicians and contained the necessary music stimuli to meet the aims of this study. Specific components were selected based on existing literature (Gfeller *et al.*, 2005; Gfeller *et al.*, 2002; Gfeller *et al.*, 1997; Gfeller & Lansing, 1991) and also on consensus between the researcher, sound engineers and musicians.

4.6.1.1.1 Purpose of the Music Perception Test

The MPT was compiled to use as data-acquisition instrument in order to obtain objective information about the influence of non-linear frequency compression on music perception.

4.6.1.1.2 Guidelines from literature for the development of the Music Perception Test

The relevance of all the sub-tests included in the MPT is corroborated by the references provided in Table 4-5.

Table 4-5: Literature references to demonstrate the importance of all the sub-tests included in the Music Perception Test

SUB-TEST	LITERATURE REFERENCE
Sub-test 1: The **rhythm identification** task required participants to determine where in a pattern of long inter-pulse intervals they perceived a short inter-pulse interval.	a) The perception of brief intervals is a pre-requisite for rhythmic precision while the perception of long intervals is necessary for keeping tempo (Rammsayer & Altenmuller, 2006:28). b) Melody recognition depends on rhythm cues (Galvin *et al.*, 2007:313). c) Adults with a hearing loss increase their reliance on temporal cues as for most hearing losses frequency resolution is lost, while temporal information remains intact (Flynn *et al.*, 2004:480). d) This was proved as an important part of rhythm perception by international studies (Rammsayer & Altenmuller, 2006; Kong *et al.*, 2004; Gfeller *et al.*, 1997) in which a similar approach was followed.
Sub-test 2: For the **rhythm discrimination** task participants were required to indicate whether pairs of rhythm sequences were the same or different.	a) See literature reference b) at Sub-test 1. b) See literature reference c) at Sub-test 1. c) Rhythm discrimination is a typical rhythm assessment task (Leal *et al.*, 2003:827). d) Rhythm discrimination was proved as an important part of rhythm perception by international studies (Cooper *et al.*, 2008; Looi *et al.*, 2008b; Leal *et al.*, 2003; Gfeller & Lansing, 1992) in which a similar task was conducted.
Sub-test 3: In the **rhythm recognition** task participants listened to two-phrase sequences played in duple or triple meter and had to indicate 'march' or 'waltz'.	a) See literature reference b) at Sub-test 1. b) See literature reference c) at Sub-test 1. c) Rhythm recognition was proved as an important part of rhythm perception by another international study (Cooper *et al.*, 2008) which included a similar task for the assessment of music perception in cochlear implantees and normal hearing listeners.
Sub-test 4: The **rhythm perception** task required participants to indicate which of two melodic sequences was played rhythmically in time.	a) See literature reference b) at Sub-test 1. b) See literature reference c) at Sub-test 1.
Sub-test 5: In the **timbre identification (single instrument)** task, a melodic sequence played by single instruments was presented to participants who had to identify the musical instrument.	a) Timbre identification was proved as an important part of timbre perception by international studies (Looi *et al.*, 2008b; Nimmons *et al.*, 2008; Leal *et al.*, 2003; Gfeller *et al.*, 2002; Fujita & Ito, 1999; Gfeller & Lansing, 1991) in which a similar task was performed.

SUB-TEST	LITERATURE REFERENCE
Sub-test 5: The **timbre identification (multiple instruments)** task asked participants to identify all the instruments that played together in different melodic sequences.	a) Timbre identification was proved as an important part of timbre perception by another international study (Looi *et al.*, 2008b) which included a similar task for the assessment of music perception in cochlear implantees.
Sub-test 6: For the **number of instruments** task participants had to indicate how many different instruments they could distinguish in a piece of music.	a) This was proved as an important part of timbre perception by another international study (Medel Medical Electronics, 2006) which included a similar task for the assessment of music perception in cochlear implantees.
Sub-test 7: In the **pitch identification** task participants were presented with a tone at the reference frequency and a higher/lower pitched tone. They were asked to identify whether the second tone was higher or lower in pitch than the first one.	a) Music perception depends on pitch cues (Galvin *et al.*, 2002:35). b) Cochlear damage leads to changes in perceived pitch or reduced pitch perception accuracy (Ricketts *et al.*, 2008:169; Moore, 1996:143). c) The ability to determine the direction of pitch change is a fundamental ability in perception of melodic contour (Gfeller *et al.*, 2002:35). d) Pitch identification was proved as an important part of pitch perception by international studies (Looi *et al.*, 2008b; Medel Medical Electronics, 2006; Leal *et al.*, 2003; Gfeller *et al.*, 2002; Vispoel & Coffman, 1994) in which a similar task was performed.
Sub-test 8: The **pitch discrimination** task required participants to determine whether a pair of melodic patterns was the same or different.	a) See literature reference b) at Sub-test 7. b) Listeners with a hearing loss make use of pitch information to assist with the identification of familiar melodies (Gfeller *et al.*, 2002:30). c) Pitch discrimination was proved as an important part of pitch perception by international studies (Medel Medical Electronics, 2006; Gfeller & Lansing, 1992) in which a similar task was performed.
Sub-test 9: The **musicality perception** task presented participants with pairs of melodic sequences and required them to indicate which of the sequences were musical.	a) Hearing loss has a significant impact on melodic perception (Gfeller & Lansing, 1992:21). b) Listeners make musical interval judgments on the basis of differences in pitch height or ratio relationships between the fundamental frequencies of notes comprising the interval (Pijl, 1997:370). c) Musicality perception was proved as an important part of melody perception by another international study (Cooper *et al.*, 2008) which included a similar task for the assessment of music perception in cochlear implantees.
Sub-test 10: For the **melody identification** task participants had to identify well-known melodies with and without rhythm cues from a closed set.	a) The rationale for testing familiar melody recognition is that not only does it efficiently test whether listeners are able to hear distinguishing features of the melody but it also tests whether listeners hear them correctly (Nimmons *et al.*, 2008:153). b) See literature reference a) at Sub-test 9. c) Melody identification was proved as an important part of melody perception by international studies (Singh *et al.*, 2009; Nimmons *et al.*, 2008; Looi *et al.*, 2008b; Galvin *et al.*, 2007; Gfeller *et al.*, 2005; Kong *et al.*, 2005; Kong *et al.*, 2004; Leal *et al.*, 2003, Gfeller *et al.*, 2002; Fujita & Ito, 1999) in which a similar task was performed.
Sub-test 11: In the **music-in-noise song identification** task participants were asked to identify movie sound tracks presented in the presence of background noise.	a) An average person daily spends roughly two hours in a car where one of the only things to do is to listen to the radio. The background noise level in most cars at 70 mph (113 km/h) is about 70 dB (A), which makes a good music-in-noise listening test (Killion, 2009:28). b) Cochlear hearing loss involves damage to outer hair cells (Moore, 1996:133) and consequences of outer hair cell loss include difficulty understanding speech, especially in background noise (Kluk & Moore, 2006: par. 5). Therefore one may assume that hearing aid users would also experience difficulty understanding music presented in the presence of background noise. c) See literature reference a) at Sub-test 9.

Table 4-5 clearly shows that all the sub-tests included in the MPT are of high importance in attempting to gain a holistic view of music perception.

4.6.1.1.3 Format of the Music Perception Test

The MPT consisted of 4 sections with a total of 11 sub-tests. The test is nine pages long and available in English only. It took participants approximately 55 minutes to complete the test. Space is provided for a respondent number to be added after completion of the test. Stimuli of the MPT were recorded on a compact disc and therefore no adaptive procedure was necessary. Instructions for the completion of the test are provided on the first page of the test and are recorded on the compact disc. All the answers in the MPT was from a closed set, requiring participants simply to selected the correct answer from the options provided. This has the advantage of restricting possible answers, making comparison of answers easier. Furthermore, it simplifies the analysis of answers (McMillan & Schumacher, 2006:197). A written response was required for each stimulus in the test. Every sub-test included two practice items preceding the actual test items. No feedback was provided during or after the test. A copy of the MPT is included in Appendix E and a copy of the marking sheet of the MPT can be found in Appendix F.

4.6.1.1.4 Content of the Music Perception Test

The MPT includes sub-tests for rhythm, timbre, pitch and melody assessment. As explained in Chapter 2, these areas were included because international research already proved the importance of these aspects in the perception of music (Deutsch, 2007:4473; Iakovides *et al.*, 2004:4). Although music cannot be fully defined by means of tests and questionnaires (Leal *et al.*, 2003:834) the researcher endeavoured to present stimuli from different parameters of music in order to obtain a more holistic picture of music perception with non-linear frequency compression hearing aids. A summary of these parameters is provided in Figure 4-2.

MUSIC PERCEPTION TEST
Compiled to evaluate the influence of non-linear frequency compression on music perception for adults with a moderate to severe hearing loss

RHYTHM
A regular movement or beat or a regular pattern of changes

Rhythm identification: Participants had to listen and determine where in a pattern of long inter-pulse intervals they perceived a short inter-pulse interval.
Rhythm discrimination: Participants had to indicate whether pairs of rhythm sequences were the same or different.
Rhythm recognition: Participants listened to two-phrase sequences played in duple or triple meter and had to indicate whether it was a march or a waltz.
Rhythm perception: Participants were required to indicate which of two melodic sequences was played rhythmically in time.

TIMBRE
The characterizing feature of a sound or pitch

Timbre identification – single instrument: A melodic sequence played by single music instruments was presented to participants and they were required to identify the music instrument they thought played from a closed set.
Timbre identification – multiple instruments: A melodic sequence played by multiple instruments was presented to the participants and they were required to identify, from a closed set, the music instruments they thought played together.
Number of instruments: Participants had to determine how many different instruments they could distinguish in a short piece of music.

PITCH
The participative impression of the highness or lowness of a sound

Pitch identification: Participants were presented with a tone at the reference frequency and a higher/lower pitched tone which were played in random order. They were asked to identify whether the second tone was higher or lower in pitch than the first tone.
Pitch discrimination: Pairs of melodic patterns were presented and participants had to determine whether the pair of stimuli were the same or different.

MELODY
A linear succession of musical tones which is perceived as a single entity

Musicality perception: Participants were presented with pairs of melodic sequences and they had to indicate which of the melodic sequences were musical.
Melody identification: Participants were asked to identify well-known melodies with and without rhythm cues from a closed set.
Music-in-noise song identification: Participants were asked to identify well-known, movie soundtracks presented in the presence of background noise from a closed set.

Figure 4-2: Schematic representation of the content of the Music Perception Test

Figure 4-2 presented a summary of the MPT. The sections that follow provide detailed descriptions of all the areas mentioned in Figure 4-2 and are described according to the different sections of the MPT which include rhythm (Section A), timbre (Section B), pitch (Section C) and melody (Section D).

Section A: Rhythm

In most rhythm related tasks, the participant is required to detect a deviation from regular periodic click-to-click intervals (Rammsayer & Altenmuller, 2006:38). This principle was applied to the rhythm identification as well as the rhythm discrimination tasks in this study. The rhythm section also included a rhythm recognition and rhythm perception task.

♬ Sub-test 1: Rhythm identification

Five groups of pulse tones (each with a duration of 1s768ms) consisting of five pulse tones (each of 43ms in duration) spaced 369ms apart from one another, except for two pulses which are grouped together with a space of 32 ms in between were presented. Pulse tones did not differ in frequency. Five different patterns were used, each distinguished by the position of the short inter-pulse interval. The first group of rhythmical patterns starts with close spacing of the tones at the beginning of the group. In the second group, two of the tones are closely spaced at the second pulse tone and the same pattern is followed for the remaining patterns. Figure 4-3 below presents a visual example of the short inter-pulse interval at position four:

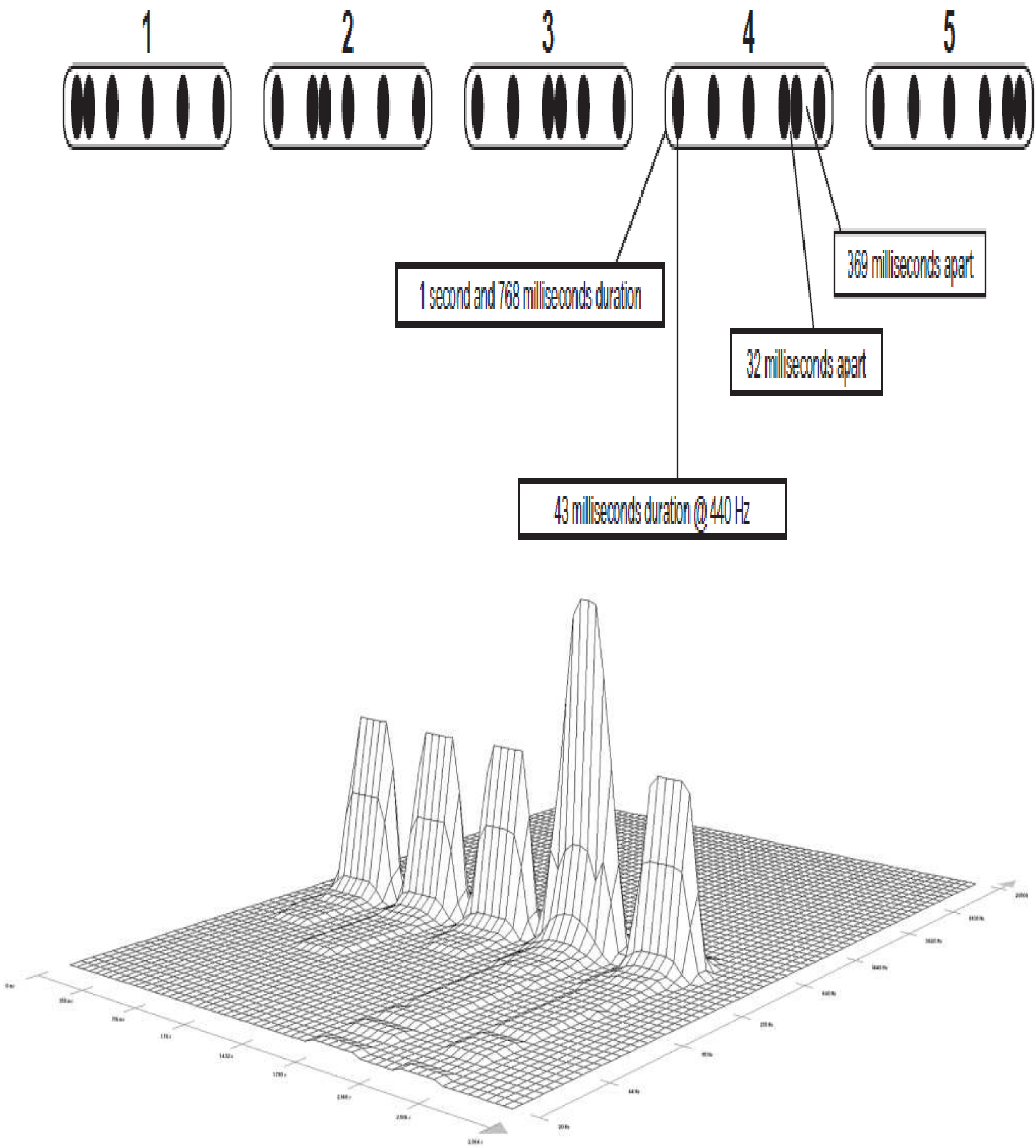


Figure 4-3: Visual representation of short inter-pulse interval at position four

Participants were provided with a visual representation of the different patterns on the answer sheet. Only *one* of the five groups was randomly played for each test, and participants were asked to identify which group they heard. To register their response, they marked the visual representation similar to the item heard with an X immediately below the representation. A total of twelve items were included in this test.

This task was similar to the six-pulse task described by Gfeller *et al.*, (1997) i.e. a given pattern consisting of six pulses separated by either of two inter-pulse intervals. Four of the inter-pulse intervals were equal in duration and called the long inter-pulse intervals. One of the intervals was shorter than the long inter-pulse interval and termed the short inter-pulse interval. The perception of brief intervals is a prerequisite for rhythmic precision while the perception of long intervals is necessary for keeping tempo (Rammsayer & Altenmuller, 2006:38). Another similar task was conducted by Rammsayer and Altenmuller (2006) in which participants were also presented with rhythmic patterns, each consisting of a sequence of clicks marking five beat-to-beat intervals. Four of the intervals were of a constant duration while one interval was variable. The participants' task was to decide whether the presented rhythmic pattern was perceived as regular (all beat-to-beat intervals appeared to be the same duration) or irregular (one beat-to-beat interval was perceived as different).

Kong *et al.*, (2004:177) conducted a closely related study in which tempo discrimination was measured. Seven one-bar rhythmic patterns using permutations of quarter, eight, and sixteenth notes were presented to the participants. All patterns were in a 4/4 time signature. In these patterns beats one, three and four always contained the same quarter note but beat two was varied to contain one of the seven possible patterns. These patterns were played at four standard tempos, namely 60, 90, 120 and 150 beats per minute. Each participant listened to two bars of drumbeats. The first bar was always a standard rhythmic pattern. The second bar contained one of the seven patterns mentioned above. Participants were asked to choose the musical notation corresponding to the rhythmic pattern they heard. For this test, all participants had to be trained to read basic music notation (Kong *et al.*, 2004:177).

♬ Sub-test 2: Rhythm discrimination

In a typical discrimination task participants are required to indicate whether pairs of sound sequences are the same or different (Leal *et al.*, 2003). This test determines participants' ability to distinguish temporal rhythms and evaluates changes in duration of notes by presenting twelve pairs of short rhythmic pulse patterns separated by five seconds of silence. All pulses were presented at the same frequency (B6 (+4 cents)/3959.8 Hz and the patterns were spaced 1.5 seconds apart. The short pulses ranged from 130 ms - 167 ms, the medium length pulses from 252 ms – 457 ms and the long pulses from 500 ms – 752 ms. The amplitude for the loud pulses was at -25.4 dB and for the soft pulses at -30.4 dB. After listening to each pair in turn, participants had to indicate whether a pair of rhythm patterns was the same or different by marking 'Yes' on the answer sheet if they were the same, or 'No' if they were different.

♬ Sub-test 3: Rhythm recognition

Participants were presented with twelve melodies in various key signatures, which were rhythmically structured as either a waltz (melodic pattern in triple meter) or a march (melodic pattern in duple meter). Melodies used in this test were specifically composed for this test and have sufficient complexity to guarantee processing as a meaningful structure rather than as a simple sequence of notes. Rhythmical patterns were varied across melodies and the tempos used varied between 100, 120, 150, 180 and 200 beats per minute. The melodies consisted of between eight and fourteen notes and were played on a piano between D4/293.7 Hz and A6/1760 Hz. A second track with rhythmical chords played on an electric piano was added to assist with the indication of the time signature (4/4 or 3/4). There was five seconds of silence after each melody. Participants indicated their response to each item by marking with an X next to the applicable answer on the provided answer sheet.

This sub-test is similar to the meter test used by Cooper *et al.* (2008) in which they evaluated the music perception of cochlear implantees and normal hearing listeners by means of the MBEA test.

♬ Sub-test 4: Rhythm perception

Participants were presented with twelve pairs of melodic sequences. In each pair, either the first or the second melody was played rhythmically out of time and would therefore not be musically rhythmical. Melodies were played on a piano with a frequency range of C5/523.3 Hz - G#6/1661 Hz. Both 4/4 and 3/4 time signatures were used and melodies were in various key signatures. The tempo range for the melodies was between 100 - 150 beats per minute. The melodies in each pair were spaced 1.5 seconds apart, with five seconds of silence after each pair. Participants were required to indicate which melodic sequence was played rhythmically in time by selecting 'First', 'Second' or 'Both' on the answer sheet.

Section B: Timbre

Timbre is defined as the characterizing feature of a sound or pitch (Brink, 1997:486). This test evaluated timbre identification with single instruments and multiple instruments playing together.

♬ Sub-test 5: Timbre identification (Part one)

This test evaluated timbre perception by requesting participants to identify single musical instruments. The timbre stimuli used in test five (Part one and Part two) included eight different musical instruments that are:

- commonly known to non-musicians (this was established through surveys of hearing and music experts and from earlier studies in which many of the same instruments have been used successfully (Gfeller *et al.*, 2002; Gfeller *et al.*, 1997; Gfeller & Lansing, 1991);
- representative of three different fundamental frequency ranges (low: 36.7 Hz – 293.7 Hz, mid: 293.7 Hz – 523.3 Hz, high: 1175 Hz - 4186 Hz);
- representative of four different instrumental families based on the principles of sound production (brass, woodwind, pitched percussion, strings).

Given the dependent variable of recognition, less commonly known instruments that could have represented a particular frequency range for a given instrumental family were not included (e.g. the viola, a mid-range string instrument, which is often confused with the violin) (Gfeller *et al.*, 2002:136). The trumpet (medium) and trombone (low) represented the brass family and the piccolo flute (high), clarinet (medium), and saxophone (low) represented the woodwind family. The string instruments were represented by the violin (high) and cello (low). Pitched percussion was represented by the piano, which was played in two different frequency ranges (medium and high). Both of these ranges are equally characteristic for the piano (Gfeller *et al.*, 2002:137). Each of these instruments was presented in its characteristic frequency range.

Past studies of timbre with adults with normal hearing have often used synthesized or highly controlled samples of isolated pitches in timbre testing (Gfeller *et al.*, 2002:137). Isolated and synthesized tones have the advantage of greater experimental control but there are difficulties extrapolating the findings from such isolated stimuli to contextualized experiences of real-life music listening or in making it ecologically valid (Gfeller *et al.*, 2002:137). Synthesized stimuli of each instrument playing the same, standardized connected melodic sequence, which include transients that are important cues for recognition, were used for this study.

The melodic pattern played by each instrument was composed specifically for use in this test. It consisted of a short melodic piece played by each instrument in C major at a tempo of 100 beats per minute. The melody consisted of seven quarter notes, each with equal length. The frequency range for each instrument is stipulated below:

- ♬ CELLO: D2/73.42 Hz - C3/130.8 Hz
- ♬ CLARINET: D4/293.7 Hz - C5/523.3 Hz
- ♬ PIANO: D4/293.7 Hz - C5/523.3 Hz & D6/1175 Hz -C7/2093 Hz
- ♬ PICCOLO FLUTE: D7/2349 Hz - C8/4186 Hz
- ♬ SAXOPHONE: D4/293.7 Hz - C5/523.3 Hz
- ♬ TROMBONE: D1/36.71 Hz - C2/65.41 Hz
- ♬ TRUMPET: D4/293.7 Hz - C5/523.3 Hz
- ♬ VIOLIN: D6/1175 Hz -C7/2093 Hz

To ensure that *identification abilities* were being assessed and not musical knowledge, each participant's familiarity with the instruments was verified before testing (Looi *et al.*, 2008b:426). Participants were given a picture of each instrument accompanied by the instrument's name. They were instructed to mark all the instruments they were familiar with sound before the onset of the test. Although instruments were chosen that were considered well-known to the general public, musical training and experiences differ considerably across the general population (Gfeller *et al.*, 2002:137). It is therefore possible that a person may be unfamiliar with one of the instruments included in the test. Instruments which an individual was not familiar with (as determined through this preliminary step) were accounted for in the analysis of the data.

After completion of the practice items, each instrument was presented twice (for a total of 16 items) in random order for identification form a closed set. After each melody was played, sufficient time was allowed for the individual to select the instrument that he/she thought produced the sound just heard. Test results were reported as a percentage correct of those instruments known by their sound (as indicated in the preliminary step referred to above).

♬ Sub-test 5: Timbre identification (Part two)

This task extended the investigation of timbre perception beyond the single-instrument identification tasks used in most previous studies and is similar to the research done by Looi *et al.*, (2008b). The additional instruments in this sub-test increased the complexity of the sound. It consisted of 16 ensembles, where different combinations of the same instruments as in the previous test played the same melodic piece in unison. Participants were asked to identify which of these instruments were playing together in each item. They had to rely on the timbre qualities of each instrument to identify them in the ensemble. Instruments were panned to various positions (from left to right) in the stereo field to help the participants in identifying them. A maximum of three and a minimum of two instruments played together. To minimize any unwanted effects of loudness cues, the levels of the four extracts of each instrument or ensemble were randomized over a 6 dB range below the participant-determined comfortable loudness level. Test results were again reported as a percentage correct of those instruments familiar by sound as indicated in the preliminary step in the previous test.

♬ Sub-test 6: Number of instruments

This test determines how many different instruments participants can distinguish in a short piece of music. Participants were presented with five different instruments (cello, piccolo, snare drum, trumpet and xylophone) each selected to have a timbre as different as possible from the others. They heard a short solo excerpt from a musical piece composed specifically for this test, played by each instrument before the onset of the actual test. Eight variations of the full piece of music (17.5 seconds in duration) played by a selection of the instruments were presented to the participants. They were asked to identify how many instruments were playing together by relying on the timbre quality and character of each instrument. Participants were required to write down the number of instruments they thought played together for each item on the answer sheet provided.

Section C: Pitch

The participative impression of the highness or lowness of a sound is called the pitch and it is known as the psychological correlate of frequency (Martin & Clark, 2000:66). The researcher determined beforehand that candidates understood the concept of 'pitch' when they explained it as 'frequency' or 'highness' or 'lowness' of a tone and differentiated it from other qualities like loudness (Fujita & Ito, 1999:634).

♬ Sub-test 7: Pitch identification

This task included discrimination of complex pitch direction change and is similar to the pitch test produced by Nimmons *et al.*, (2008). As mentioned previously, music perception depends strongly on pitch cues (Galvin *et al.*, 2007:303) and the ability to determine the direction of pitch change is a fundamental ability in perception of melodic contour (Gfeller, *et al.*, 2002:35).

Participants were presented with pairs of two tones each, generated by a combined Saw Square wave which has been shaped by a filter to produce a synthetic tone close to that of a piano. Digitally synthesized complex tones were chosen because they are representative of real-world acoustic tones in which fundamental frequency and overtone information are relevant cues for pitch discrimination (Nimmons *et al.*, 2008:151). The synthetic tones had identical spectral envelopes derived from a recorded piano note at middle C (262 Hz) and uniform synthetic temporal envelopes to eliminate any temporal envelope cues that might be present. Each tone had a duration of 934 milliseconds. Each pair consisted of a base tone of F#4/370 Hz, C3/130.8 Hz, E3/164.8 Hz or G3/196 Hz. A second tone ranging between D4/293.7 Hz and G5/784 Hz followed after 1.5 seconds of silence and was either higher or lower than the base tone, in a range of one semitone to 12 semitones.

The pitch direction test was implemented using a two-alternative, forced-choice test. On each presentation, a tone at the reference frequency and a higher/lower pitched tone were played in random order. Participants had to identify whether the second tone was higher or lower than the base tone. Each pair was separated by five seconds of silence.

Many studies of music have focused on pitch perception, identification or discrimination tasks (Limb, 2006:441) and similar pitch tests were done by Looi *et al.* (2008b); Leal *et al.* (2003); Medel Medical Electronics (2006); Gfeller *et al.* (2002); Moore and Peters (1992) as well as Vispoel and Coffman (1994) who conducted pitch tests where examinees had to indicate if the pitch became higher or lower or in which of two pairs one of the tones was higher than the other.

♬ Sub-test 8: Pitch discrimination

This test determines a participant's ability to distinguish differences between pitch. Participants were presented with twelve pairs of short melodic sequences (consisting of two to five notes). The melodies were played on a piano in a range of C5/523.3 Hz - A7/3520 Hz at a tempo of 80 beats per minute. The item pairs have equivalent rhythmic patterns; however, those item pairs that are 'different' vary in frequency on one or more notes. The differences within the pairs vary from gross differences to extremely subtle ones where only a single note is being flattened. The melodies in each pair were separated by 2.5 seconds of silence. Each pair is separated by five seconds of silence. Participants were asked to indicate whether the melodic sequences in each pair were the same or different. They indicated their answer by selecting 'Yes' if they were the same or 'No' if they were different.

Section D: Melody

A melody, also tune, voice or line, is a linear succession of musical tones which is perceived as a single entity (Brink, 1997:301). This section includes musicality perception, melody identification and music-in-noise song identification tasks.

♬ Sub-test 9: Musicality perception

Participants were presented with twelve pairs of short melodic sequences (two to four bars long). The melodies were played on a piano in a range of C#5/554.4 Hz - B6/1976 Hz at tempos ranging from 90 to 160 beats per minute. Melodies were played in various key and time signatures (4/4 and 3/4) to make the test more interesting. Some of the melodies in the pairs were random notes, making no musical sense, while others were musical pieces with a clear melodic structure. Participants had to indicate which of the melodic sequences were musical. In some pairs, both pieces were melodic while in other pairs none were melodic. The sequences were separated by 1.5 seconds of silence and each pair by five seconds of silence.

♬ Sub-test 10: Melody identification

The rationale for testing familiar melody recognition is that not only does it efficiently test whether listeners are able to hear distinguishing features of the melody but it also tests whether listeners hear them correctly (Nimmons *et al.*, 2008:153). For example, misperceiving any part of the melody (the component pitches, the pitch interval changes, or the overall melodic contour) can completely change the melody. Recognition is a high-level task that is expected to be difficult, and yet, fundamental properties in their combined music and cultural exposure enable adults with normal hearing to identify melodies with high levels of accuracy (Nimmons *et al.*, 2008:153).

The term 'melody test' is arguably a misnomer because real melodies have varying durations and may have accompanying lyrics (Nimmons *et al.*, 2008:153). These are important cues for song recognition that were intentionally omitted in this study because the focus was on the recognition of pitch and pitch patterns as, since these are poorly represented and are implicated in other important skills such as perception of speech in noise, understanding of tonal languages, and sound localization.

Many studies of music have focused on melody perception and discrimination tasks (Limb, 2006:441). In this sub-test participants were asked to identify common melodies with and without rhythm cues from a closed set. The melodies were selected for their general familiarity as determined through discussions among hearing and music professionals, and also from earlier studies in which recognition tests demonstrated that the melodies were familiar for persons with normal hearing and cochlear implantees (Kong *et al.*, 2005; Looi *et al.*, 2008b). To maximize cross-cultural recognition, input was solicited from individuals from different ethnic backgrounds. All the melodies were truncated at 12 to 15 notes to prevent song length as a potential cue (Nimmons *et al.*, 2008:151). To eliminate rhythm cues for melody recognition the melodies were created by repeating all longer notes in an eight-note pattern, yielding isochronous melodies.

Before testing, the participants were presented with an alphabetical list of the names of ten well-known melodies and were asked to indicate their familiarity with each song. This was done to ensure that it was *identification* abilities being assessed and not musical knowledge (Looi *et al.*, 2008b:426). The melodies were played on a piano in a range of A5/880 Hz – C8/4186 Hz. The stimulus set contained two presentations of each of the ten melodies. Each melody was presented with its rhythmical structure intact and again where each note had a duration of 400 milliseconds, leaving the structure of the melody intact with only pitch as a cue for melody identification (meaning that there was no rhythmical structure). The playing of the melodies was randomized, but each melody was played twice, once rhythmically intact and once not. After two practice items participants were asked to identify the melody on both occasions from a closed set. Participants responded by writing the number corresponding to the melody title they heard on the answer sheet. Participants were allowed to request that the melodies be repeated a maximum of three times. The final score was reported as a percentage of correct responses on the melodies with which the listener was familiar. Missed items were cross checked with the list completed beforehand. If an item was missed, and it was not listed as familiar, that item was eliminated from the analysis.

It is difficult to select one exemplar melody that represents the entire corpus of melodies familiar to South African adults. Individual melodies vary considerably from one another in the total frequency range as well as interval changes from one note to the next. Prior research indicates that some particular melodies may be more difficult than others to recognize under degraded conditions (Gfeller *et al.*, 2002:35). From the standpoint of hearing aids, wearers vary considerably in their ability to discriminate pitches, demonstrate intra-participant differences across different frequency bands, and show more or less orderly relations between frequency and pitch. Thus, the interaction between particular melodic features and individual performance is impossible to predict. Therefore, the researcher included ten familiar melodies that represented a variety of melodic features, thereby rendering a more realistic representation of how persons with hearing aids may function across a range of items.

A limitation of melody identification tasks is that the test assumes previous knowledge of the songs (Nimmons *et al.*, 2008:153). The test, then, might not be valid for pre-lingually deafened individuals but no persons with a pre-lingual hearing loss were included in this study. The familiarity factor is difficult to control but in an attempt to limit this effect extremely common melodies were selected. The melodies included:

- '7de Laan' theme song (Theme song of a most popular TV soap in South Africa)
- Happy birthday to you
- Jingle Bells
- Mary had a little lamb
- 'Nkosi Sikelel' iAfrica' (South African national anthem)
- *Nokia* ring tone (Popular cell phone ring tone in South Africa)
- Old MacDonald had a farm
- Twinkle, twinkle little star

- ♬ Wish you a merry Christmas
- ♬ Wedding march (Composed by Felix Mendelssohn)

Furthermore, in recall tasks, the 'tip-of-the-tongue' phenomenon is a commonplace occurrence (Gfeller *et al.*, 2002:37). This is when a particular melody may be truly familiar, but the person is unable to retrieve from long-term memory the actual title of the melody. For this reason a structured response protocol that provided alternative categories of responses was used to assist the respondent in the recall of truly familiar items. If the respondent could not recall the exact title, they were asked if they recalled lyrics form the song, or finally, the topic or occasion associated with the song (e.g. for the song 'Wedding March' the response could be 'getting married').

♬ Sub-test 11: Music in noise song identification

A need expressed by Killion (2009:24) states that since we are stuck with human ears and brains, the challenge is to find a collection of sound samples that can be used by patients and audiologists to rate the suitability of hearing aid fittings for music processing within a few minutes. This sub-test aimed at providing evaluation material that are representative of real-life experiences and will therefore be able to give information on hearing aid processing in a real-life situation. Killion (2009:28) used an informal listening test to evaluate the suitability of a hearing aid for reproducing music. These musical materials included singing, playing a piano, a high quality violin, a trumpet, and listening to music in a car.

Stimuli used in this sub-test were 'real-word music', which is explained as excerpts from recordings of music that can be heard through popular media sources in everyday life (Gfeller *et al.*, 2005:240). The selection of naturalistic, 'real-world' musical stimuli for test purposes is challenging, given the seemingly infinite combinations of structural features in music, as well as the range of listening experiences that potential participants may bring to the testing situation. The researcher decided to include familiar film soundtracks. By doing this the researcher aimed at enlarging the possibility of participants being familiar with the songs since they are available on radio but can also be heard when watching movies.

There are thousands of compositions from musical tracks used in movies from which to choose test excerpts. As musical experiences vary considerably from one person to the next, and because recognition requires familiarity, a systematic process of selecting items that were likely to be familiar to many South Africans was used. Briefly, compositions were selected using published rankings of exposure and popularity, which offered quantifiable evidence of item exposure and familiarity to a relatively large segment of the adult South African population. Some of the included melodies have been found to be familiar by Spitzer *et al.* (2008) although they targeted the United States population. Table 4-6 presents the songs included in this sub-test:

Table 4-6: Songs included for the music-in-noise sub-test

Songs included	Film	Song titles included in list but not used as stimuli in test	Film
Beauty and the Beast	Beauty and the Beast	A whole new world	Aladdin
Chariots of fire	Chariots of fire	Climb every mountain	Sound of music
Don't cry for me Argentina	Evita	Hungry eyes	Dirty dancing
I've had the time of my life	Dirty dancing	I finally found someone	The mirror has two faces
Leaving on a jet plane	Armageddon	I say a little prayer for you	My best friend's wedding
My heart will go on	Titanic	Diamonds are forever	Diamonds are forever
Purple rain	Purple rain	Lara's theme	Doctor Zhivago
Singing in the rain	Singing in the rain	Pink Panther theme	Pink Panther
Unchained melody	Ghost	Summer nights	Grease
Stayin' alive	Saturday night fever	Take my breath away	Top Gun

Because musical training and experience are unevenly distributed among the general population, it is possible that an individual may have no prior exposure to, and therefore is unfamiliar with a specific item in the test, despite the fact that the excerpt is well-known to the general public (Gfeller *et al.*, 2005:242). Therefore, to rule out lack of familiarity as a factor in item recognition, an alphabetized list of melodies was included to identify the songs known to participants. This list included 20 well-known movie soundtracks of which only ten were included as test stimuli.

An average person spends between two and a half to three hours in a car daily. This is due largely to the factors of traffic congestion and urban sprawl. While driving, one of the only things to do is to listen to the radio, mostly playing music. The background noise level in most cars at 70 mph (113 km/h) is about 70 dB (A), which makes for a good music-in-noise listening test (Killion, 2009:28). The researcher therefore decided to compile a music-in-noise test as part of this test battery to simulate a real life situation for listening to music. For this purpose a simulated noisy environment, namely that of the interior of a car driving in traffic, was created to mask ten of the songs. A difference of 6.2 dB and 10.2 dB was determined between the peak loudness of the music and the peak loudness of the noise which peaks at 0 dB. Only a well-known section (20 seconds, with 4 second fade in and 4 second fade out) of each song was played. The songs were separated by ten seconds of interior car noise only.

Before testing took place, participants had to indicate which soundtracks they were familiar with. They were asked to identify the soundtracks by writing the corresponding number on the answer sheets. No evidence of such a test could be found in the literature.

4.6.1.1.5 Reliability and validity of the Music Perception Test

The reliability and validity of the MPT would influence the extent to which important information could be obtained from the study, the probability to obtain statistical significance in data analysis and the extent to which meaningful conclusions could be drawn from the collected data (Leedy & Ormrod, 2004:29). Several measures were taken to increase the reliability and validity of the MPT as discussed below:

Reliability means that results are replicable and therefore, when administered properly, a test will render consistent results on repeated administrations or with different interpreters judging the same administration (Shipley & McAfee, 2008:6). To obtain reliability to the highest possible degree, the following measures were implemented:

- A thorough study of previous music perception tests described in the literature was conducted. This enabled the researcher to make informed decisions on material to be included in the MPT.

- By conducting the MPT on persons with normal hearing, preliminary norms for this test were compiled. This also enabled the researcher to compare the results of the participants with a hearing loss to those of normal hearing listeners.
- In order to control for central auditory processing disorders, an inter-subject analysis was used. When the results of a person with central auditory processing disorder are compared to those of a person without central auditory processing disorder the results might not be reliable, since the presence of central auditory processing disorders might be the cause of poor performance on the test. By comparing each participant's data with itself the reliability of the results of the MPT was improved.
- Rater-reliability refers to the degree to which the same person or different people obtain the same or very similar results after administering a test (Shipley & McAfee, 2008:6). Intra-rater reliability was established as the test results were consistent when the researcher administered the test on more than one occasion, i.e. participants that scored high the first time also scored high the second time and vice versa.
- Agreement as coefficient of reliability refers to the extent to which two or more persons agree about what they have rated (McMillan & Schumacher, 2006:186). In the current study, professionals in the music and audiology industry provided similar ratings for different aspects of the MPT. This agreement in ratings therefore improved the reliability of the test.

As the purpose of the study was to determine the influence of non-linear frequency compression on music perception and not to develop a test for the assessment of music perception, the MPT was not administered multiple times to the same group of people in order to compare their results. Therefore test-retest reliability was not obtained but, as mentioned before, this was outside the scope of the current study. Furthermore, inter-rater reliability could not be obtained because the researcher was the only audiologist available to perform testing and therefore the test could not be administered by various persons. Lastly, parallel reliability, also known as alternate reliability, could not be obtained as there is no music perception test for hearing aid users available to compare the newly compiled test (MPT) to (Shipley & McAfee, 2008:6).

Validity means that a test truly measures what it claims to measure (Shipley and McAfee, 2008:5). The following steps were taken to validate the MPT (Downing & Haladyna, 1997:64-71):

- The content of the test was defined by documenting the selection of items and the methods used. Additional aspects implemented in the development of the content of the test, and aiming at optimizing its validity, were the following:

    - The high quality of the MPT recordings contributed to the validity of the test and to the results of the study since the test was recorded in a professional music studio by professional musicians and sound engineers.
    - Wherever possible, the stimuli have been recorded to render a range from gross differences to very subtle changes. By their very nature, speech tests evaluate performance and are susceptible to ceiling affects, but differences in musical stimuli can be so subtle that many normal hearing listeners might be stretched to recognize them (Medel Medical Electronics, 2006:1).
    - Where applicable, piano tones were used for stimuli in the MPT since piano tones are more commonly available in music. Due to their ecological validity they are therefore typically used in music perception tasks (Cooper *et al.*, 2008:625).
    - A calibration tone was inserted at the beginning of the recording and the alerting phrase 'Are you ready?' was inserted prior to each test. Recognizing that music is highly variable in intensity, care was taken to maintain a minimum intensity level within 10 dB of the calibration tone.
    - Recordings were consistent in terms of characteristics. If the duration of a given excerpt is long, it is likely that the timbre and spatial characteristics will vary in time and listeners might find it difficult to 'average' the quality over time and random errors may occur (Zielinski, Rumsey & Bech, 2008:431). Therefore short and consistent stimuli were used in the MPT.
    - The researcher obtained objective results with the test and did not make use of affective judgments. The long-term stability of affective judgments is poor as listeners preferences may drift over time due to, for instance, changes in fashion, changes in listening habits or

changes in the technical quality of available products (Zielinski *et al.*, 2008:433). Furthermore, listeners' affective judgments may also be biased by the appearance of the equipment, the price of the hearing aids and branding (Zielinski, 2008:433).

- Test specifications were constructed by documentation of specifications for the test and form part of the MPT manual that is available in Appendix H.
- Item content verification was provided. This was done by providing a reference list of sources used in the development of the MPT as well as a peer content review. The peer content review was conducted in the form of a rating scale to verify the quality of included items as well as the relevance of the test to the field being assessed. A copy of the evaluation sheet used for the peer content review is provided in Appendix I. Various aspects were addressed in the MPT evaluation sheet which, after completion by professionals in the audiology and music industry, provided the following aspects of test validity (Shipley & McAfee, 2008:5-6):

  - Face validity – this implies that the MPT, based on its appearance, seemed to measure what it claimed to measure.
  - Content validity – this refers to the completeness of the MPT as a valid test for the assessment of music perception on the grounds of the entire spectrum of skills that are tested which included rhythm, timbre, pitch and melody.
  - Construct validity – this refers to the MPT's ability to measure a predetermined theoretical construct, in this case music perception, which is an explanation of a behaviour or attribute based on empirical observations.
  - Criterion validity – this implies validity of the MPT as established by the use of external criteria obtained from the peer review.

- Editing of test items. By reviewing items, the clarity and appearance of items were enhanced. This was done in Stage 2 of the first phase where items with high error rates were rejected. A copy of the first version of the MPT can be found in Appendix G and include the original items before item editing was done. All items that needed editing were professionally edited.
- The test was reviewed to identify bias-sensitivity since one source of invalidity could be measurement error caused by the language used in the test. A thorough and systematic review

of the test items for potentially biased words, phrases, situations or content was done in order to eliminate potential culturally biased words, phrases and situations that might be offensive to some individuals. This was done by presenting the test to a mix of racial and ethnic groups. An exact match of the South African demographics could not be obtained, but Downing and Haladyna (1997:70) indicated that an exact match to the demographics of the target examinees is unnecessary.

- Items were tried out and pre-tested in the pilot study, thereby enhancing item validity. Subsequently item analysis-type data were calculated and the performance characteristics of the items such as item difficulty were assessed. The pilot study enhanced the validity of the test as it gave an indication of the effectiveness of the test. Furthermore, by validating the results of the MPT, the reliability of the test was increased, giving it more feasibility and utility.
- Lastly, test security of items was ensured. This is an essential element in the validity of examinations as invalidity is introduced to the test when some examinees have access to test items whilst others do not. The researcher ensured that the examination was secure and that careful documentation, record keeping and a method of systematic routine reporting of documentation took place.

The use of a test like the MPT may however have pitfalls. Most notably, there is likely to be a *cultural specificity* to the items selected (Spitzer *et al.*, 2008:63). Furthermore, *familiarity with melodies* may be affected by access, both on the basis of national origin as well as listening experience resulting from hearing loss or other factors. To maximize cross-cultural recognition, input was solicited from individuals from different cultural backgrounds for Sub-test 10 (Melody identification) and Sub-test 11 (Music-in-noise song identification). This was done by providing them with a list of 25 well-known songs and asking them to select the ten songs with which they were the most familiar. Furthermore, very early *onset of deafness* may effectively eliminate the ability to respond to certain stimuli in this test, therefore no pre-lingually deafened adults were included in this study. Another issue is that the ability to perform well on a music perception test does not imply *musical satisfaction* (Spitzer *et al.*, 2008:63). In an attempt to compensate for this, each participant also completed questionnaires to give a subjective impression on how they perceived musical stimuli with the hearing aids. Lastly, random errors are commonly observed in the results of listening tests as they manifest themselves by a scatter of scores for a given experimental condition. These errors are predominantly caused by inconsistency of individual listeners in the assessment of audio quality and they may also originate from inter-listener differences in the evaluation of audio quality (Zielinski *et al.*, 2008:427).

4.6.1.2 Questionnaires

A questionnaire is defined as a set of questions on a form to be completed by targeted persons for the purpose of research (McMillan & Schumacher, 2006:194). Self-report questionnaires and inventories to assess performance with assistive devices have a long and honourable history (Gatehouse & Akeroyd, 2006:98) and are often used to evaluate the success of hearing aid fittings (Bentler, 2006:89). Such questionnaires usually take the form of presenting the respondent with a list of scenarios which he/she is asked to rate on one or more dimensions, usually via some form of fixed scale or response alternatives (Gatehouse & Akeroyd, 2006:98).

Due to a shortage of available material to attain the aims of this study, it was necessary to design appropriate questionnaires. The questionnaires were designed by the researcher and contained the information needed to reach the aims of this study. The researcher made use of two questionnaires. After the hearing aid fitting questionnaires were handed to each participant to be completed personally in a verification session and in the presence of the researcher. This procedure ensured personal contact and subsequent higher response rates (Delport, 2005:168). This is seen as an advantage, because a low response rate, as often found with mailed questionnaires, impacts negatively on the quality of the research (Bless & Higson-Smith, 2000:109).

4.6.1.2.1 Motivation for the use of questionnaires

There are several advantages to the use of a questionnaire. A questionnaire is relatively economical, provides the same questions to all subjects and can ensure anonymity (McMillan & Schumacher, 2006:194). The participant further requires little (if any) training to complete the questionnaire and tends to give more honest opinions during the completion of a questionnaire than during an interview. If the instructions and questions in a questionnaire are clearly formulated, the information obtained may be viewed as accurate and valid as it was personally provided by the participant (McMillan & Schumacher, 2006:195).

There are, however, some drawbacks to the use of questionnaires of which one of the most common is the often encountered low response rates which may negatively influence the quality of the research (Maxwell & Satake, 2006:225). In this study, however, high response rates were ensured by having respondents complete the questionnaires in the presence of the researcher before they left the facility. In compiling the questionnaires the researcher also implemented several guidelines from literature which facilitated completion, thereby optimizing the response rate. Still another disadvantage of questionnaires is that it often provides a limited view of some aspects because participants are not given the opportunity to address additional aspects (Maxwell & Satake, 2006:226). To minimize this phenomenon, participants were provided ample space to motivate or comment on their answers; the questionnaires also included a question where participants had the opportunity to provide additional information.

4.6.1.2.2 Guidelines provided by literature for the development of questionnaires

By structuring and grouping questions to logically follow on each other, a well constructed questionnaire will form an integrated, holistic unit. Some of the main principles that items in a questionnaire should comply with is that it should be based on clearly defined objectives; it should also be clear, relevant, short and uncluttered (McMillan & Schumacher, 2006:210). Furthermore, biased items and terms should be avoided. If the questions are constructed according to these guidelines, they will provide valid and reliable data after completion and analysis (McMillan & Schumacher, 2006:210).

To ensure participation and increase the response rate of the questionnaires, the following guidelines were followed in the construction of the questionnaires (McMillan & Schumacher, 2006:194-203; Maxwell & Satake, 2006:225-231):

- Participants were provided with a letter requesting informed consent beforehand. This letter explained the purpose and procedures of the study and ensured that participation would be voluntary.
- Indications of the time it will take to complete the questionnaires were also provided in the aforementioned letter. This was made possible conducting a pilot study before the main study commenced.
- Clear and simple instructions were provided at the beginning of the questionnaires.
- Relevant questions were grouped together and questions were organized in a logical sequence.
- Double-barrelled and lengthy questions were avoided.
- Biased questions were avoided and the researcher formulated questions in such a way that there was no hint for a certain response.
- The first part of the questionnaires consisted of more general questions while more sensitive questions were placed towards the end of the questionnaires.

4.6.1.2.3 Description of questionnaires

The first questionnaire consisted of 17 questions and the second questionnaire of nine. Both questionnaires were two pages long, consisting of one section and available in English only. Each questionnaire took approximately ten minutes to complete. The questions were logically organized to provide structure to the questionnaire, to orientate participants and to simplify analysis. The questionnaires provided space for a respondent number; this was added after completion of the questionnaires. On the right hand side of the questionnaire the usual space for coding, with the heading 'For office use only', was provided. Instructions for the completion of the questionnaires were provided to each participant. A copy of Questionnaire 1 is provided in Appendix J and of Questionnaire 2 in Appendix K.

4.6.1.2.4 Purpose and content of the questionnaires

The following information was included in the questionnaires:

Questionnaire 1: This questionnaire aimed at obtaining information regarding the participants' musical background as this might influence the results of the study and assist in the interpretation of the obtained results. It was the first questionnaire handed to the participants for completion, the assumption being that non-deceptive and relative easy questions may act as ice breakers and motivate participants to further complete the questionnaire (Singleton, Straits & Straits, 1993:154).

The first seven questions requested information regarding participants' musical background, whether they received any musical training or participates/d in any musical activities. The next six questions obtained information about the importance of music in the participant's daily living and provides data on musical preferences that the participant might have. These questions were included to assist with the interpretation of the results of the MPT because music skills may cause participants to perform better on the test. Lastly, participants were asked about their musical experiences when listened to with their hearing aids on. This rendered valuable information regarding current difficulties participants might experience when listening to music with hearing aids, and highlights aspects to which the researcher should pay attention when evaluating music perception with the non-linear frequency compression hearing aids. The last question gave participants the opportunity to add, should they wanted to, any additional related information. The rationale for including the last mentioned question is to give participants the opportunity to expand or provide information that wasn't necessarily targeted in the questionnaire, but could assist in the analysis and interpretation of the results (Singleton *et al.*, 1993:59).

Table 4-7 provides a presumption and literature reference for all the questions included in the first questionnaire. Information obtained through this questionnaire enabled the researcher to orientate herself regarding the participants and facilitated analysis and interpretation of the results of the study.

Table 4-7: Presumptions and literature references for questions included in Questionnaire 1

	QUESTION	PRESUMPTION	LITERATURE REFERENCE
1	For approximately how many years did you receive musical training (instrument and/or voice lessons)?	People with musical training will perform better on different tasks of music perception than people with no musical training.	♬ Previous research has identified factors influencing music processing that include **music background and training** (Kreutz *et al.*, 2008:58). ♬ It has been found that **music training** improves the processing of tonal music in the left hemisphere (Van Egmond & Boswijk, 2007:31). ♬ **Training** specific to music perception can improve scores on music perception tests (Cooper *et al.*, 2008:624). ♬ The ability to detect musical aberrations is likely to be dependent on cultural musical upbringing, degree of innate musicality, presence of tone deafness, and degree of **musical training** (Limb, 2006:438). ♬ Precise judgments of interval size require listeners to have received considerable **formal musical training** (McDermott, 2004:66). ♬ Musicians' superior performance on perceptual temporal tasks that do not require reference memory processes, suggests that **extensive music training** may exert a positive effect on timing performance by reducing variability or noise associated with the timing process (Rammsayer & Altenmuller, 2006:42). ♬ It was found that subjects with **musical training** were more capable in recognizing nursery songs, both with and without vocal elements (Leal *et al.*, 2003:834). ♬ **Formal musical training** in high school, college and beyond was found to be a significant predictor for music perception where the listener must rely on spectral information (Gfeller *et al.*, 2008:132). ♬ Respondents with **musical training** were more likely to report a loss in their enjoyment of music since developing a hearing loss (Leek, Molis, Kubli & Tufts, 2008:520).
2	Please specify the musical instruments that you are currently playing, or have played before.	People who are able to play any musical instrument/s might perform better on certain tasks of music perception, especially related to timbre.	♬ Results do not necessarily indicate that **instrument training** or ear training does not improve one's performance in experimental tasks, but some listeners' aptitude for tonic identification seems to be higher. Consequently, these listeners need less music training to reach the same skill level than less talented listeners (Van Egmond & Boswijk, 2007:34). ♬ Trainee factors can affect the rate of learning in auditory rehabilitation. For example, life experiences in music listening and the **knowledge of musical instruments** prior to and throughout training can influence rehabilitative benefit (Driscoll *et al.*, 2009:73).
3	Do you currently sing, or have you ever sung, in a choir or at social/professional gatherings?	People that are singing or have sung on a more formal level might perform better on certain tasks of music perception as this indicates a high probability of having musical talent.	♬ Results do not necessarily indicate that instrument training or **ear training** does not improve one's performance in experimental tasks, but some listeners' aptitude for tonic identification seems to be higher. Consequently, these listeners need less music training to reach the same skill level than less talented listeners (Van Egmond & Boswijk, 2007:34).
4	Please specify your highest musical qualification.	A person with a higher musical qualification will perform better on different tasks of music perception than a person with no musical qualification. People with formal musical training will evaluate the quality of music in a more strict matter.	♬ See literature references at Question 1.

QUESTION		PRESUMPTION	LITERATURE REFERENCE
5	Do you consider yourself to be a person with musical talent or musical sense?	If one considers him/herself or other people consider him/her as a person with musical talent or musical sense and this person do not have any formal musical training, it might be that he/she can still perform better on certain aspects of music perception compared to a person who is not considered to be musical.	♬ Another factor that may affect scores on music perception tests is the **musicianship** of the participant (Cooper *et al.*, 2008:624).
6	Do other people consider you to be a person with musical talent or musical sense?		
7	Please specify your relationship to any persons in your immediate family with an extraordinary musical talent?	A person who has an immediate family member with extraordinary musical talent might have a genetic predisposition to perform better in certain tasks of musical perception, especially pitch-related tasks.	♬ Auditory testing of siblings of individuals who score exceptionally well on formalized auditory tests of pitch perception indicates that absolute pitch **aggregates in families** (Baharloo, Service, Risch, Gitschier & Freimer, 2000: 758). ♬ Music perception and creativity in music are linked to the same phenotypic spectrum of human cognitive social skills, like human bonding and altruism both associated with **AVPR1A chromosome** (Ukkola, Onkamo, Raijas, Karma & Jarvela, 2009:1).
8	What role does music play in your life?	A person that is more exposed to music, demonstrates a greater interest in music and spent more time listening to music will be more 'trained' (trained ear) to evaluate music and participate in certain tasks of music perception for example familiar melody identification.	♬ Predictors related to musical training and **experience** included: **music listening habits**, amount of formal musical instruction in elementary school, and amount of formal music instruction in high school and beyond (Gfeller *et al.*, 2010:31). ♬ Trainee factors can affect the rate of learning in auditory rehabilitation. For example, **life experiences in music listening** and the knowledge of musical instruments prior to and throughout training can influence rehabilitative benefit (Driscoll *et al.*, 2009:73). ♬ Cochlear implant users' music perception may be greatly improved with training and **music listening experience** (Galvin *et al.*, 2007:312). This should be investigated for hearing aid users.
9	How often do you listen to music?		
10	How many hours do you usually listen to music on a work day?		
11	How many hours do you usually listen to music on a day that you are not working (for example over weekends)?		
12	In which situations do you listen to music?	The situations in which a person listens to music might influence his/her enjoyment of music and the musical quality he/she perceives.	♬ Listening to music is an important part of life and most often music is recorded and played on a **CD player**, the **radio**, the **television**, an **MP3 player**, or a **computer** (Minnaar, 2010:38). ♬ Many respondents indicated they listened to music on the **radio** and **television**, two media which typically use only one sound source for both music and lyrics. The task of understanding lyrics then becomes one of separating a speech signal (lyrics) form a background (music), nearly always a challenge for people with hearing loss (Leek *et al.*, 2008:525).
13	Which music genre/s do you listen to?	The musical genre/s a person is exposed to can influence his/her performance on different tasks of music perception for example a person who listens to classical music might perform better on timbre identification tasks.	A continuum of simple to complex compositions can be found within all three (**pop, country** and **classical**) of these genres. However, in general, classical selections tend to have more complex, sophisticated melodic, harmonic and rhythmic structures than those found in typical pop and country favourites. For example, structural analysis of many pop and country pieces reveals a predominately homophonic structure (a predominant melody line over a harmonic progression in a rhythm similar to that of the melody), relatively simple and redundant harmonic progressions and repetitive rhythmic patterns. These characteristics contrast with the complex harmonic progressions (e.g. deceptive cadences, complex and rapid tonal modulations, counterpoint, etc.) intricate rhythms, and sometimes timbre blends of large classical compositions (Gfeller *et al.*, 2005:241).

QUESTION		PRESUMPTION	LITERATURE REFERENCE
14	Do you feel that your enjoyment of music has decreased since you started experiencing hearing problems?	People with a hearing loss will complain of a decrease in enjoyment of music.	♬ Hard-of-hearing musicians have long complained about the **poor sound quality** they experience while playing their instruments or when listening to music through hearing aids. Indeed, many non-musicians also complain of the **reduced sound quality of music** heard through their personal amplification (Wessel *et al.*, 2007:1; Chasin, 2003b:36). ♬ Respondents with musical training were more likely to report a **loss in their enjoyment** of music since developing a hearing loss (Leek *et al.*, 2008:520).
15	Do you remove your hearing aid when you listen to music?	Most people remove their hearing aids when they listen to music.	♬ People complained about the reduced sound quality of music heard through hearing aids to such an extent that hearing aid users often prefer to **remove their hearing aids** when listening to music (Wessel *et al.*, 2007:1; Chasin, 2003b:36).
16	What do you find most annoying when you listen to music with your hearing aid?	Hearing aid users will have difficulty understanding the words of songs.	♬ 79% of respondents felt that their hearing loss hindered their enjoyment of music. Complaints included **difficulty understanding the words** of songs as well as **distortions of pitch and melody** (Leek *et al.*, 2008:521). ♬ The two complaints that were most commonly voiced were that the music was either **too loud or too soft overall** or that it was **difficult to understand the words** in the music. Other complaints included **difficulty to recognize melodies** and **volume changes in music** (Leek *et al.*, 2008:523).

The table above summarizes the information included in the first questionnaire and highlights its importance.

Questionnaire 2: The second questionnaire was in the form of a self-report questionnaire and was designed with the purpose of obtaining subjective information form participants regarding their experience with the non-linear frequency compression hearing aids while engaging in different musical activities. Through the second questionnaire the researcher obtained subjective information about the participants' hearing aid preferences when listening to music and this information could assist the researcher in evaluating the efficacy of these amplification devices for musical stimuli (Auriemmo *et al*, 2008:50). The questions in this questionnaire were revised from the Munich Music Questionnaire (Medel Medical Electronics, 2006) used to evaluate the listening habits of people with post-lingual deafness after cochlear implantation and a five-point perceptual scale used by Chasin (2003b:38) to obtain measures of sound quality. This five-point scale used by Chasin (2003b) is a modification of the work of Gabrielsson and colleagues and has been used extensively in the hearing aid industry (Chasin, 2003b:38).

The first question determined the participant's favourite musical genre and is similar to a question form the Munich Music Questionnaire. The second question was divided into eight subquestions, each obtaining measures of sound quality. Participants were asked to rate the sound from 1 (poorest) to 5 (best) on eight perceptual scales. The first five perceptual scales (Loudness, Fullness, Crispness, Naturalness and Overall fidelity) are similar to the ones used by Chasin (2003b:38) while the following three perceptual scales (Pleasantness, Tinniness and Reverberant) were adapted from the Munich Music Questionnaire. The following five questions were directed towards specific musical discriminations that participants could or could not detect, for example to discriminate between different musical instruments, high and low notes, the lyrics of a song, etc. The second last question left space for additional comments that the participants might wanted to add and in the last question participants were provided the opportunity to indicate whether they would like to receive the results of the study or not.

4.6.1.2.5 Format of questionnaires

In both of the questionnaires the researcher included more closed ended questions because they make for more effective data acquisition, data processing and data analysis (Leedy & Ormrod, 2005:113). However, the researcher did not use closed ended questions exclusively, as this may provide insufficient results in some cases due to participants possibly not agreeing with the answers provided (Leedy & Ormrod, 2005:110). In the case of closed ended questions the participant is expected to select an appropriate answer from a list of specified options, whereas in the case of open ended questions the participant is expected to formulate his/her own answer. The use of open ended questions might however make comparison of responses between respondents more difficult (Leedy & Ormrod, 2005:114).

The use of closed ended questions has the following advantages (McMillan & Schumacher, 2006:197; Leedy & Ormrod, 2005:110):

- Participants find it easier to understand the meaning of a question because the provision of possible answers limits the participant’s choices.
- Participants find it easier to answer because they only have to select one of the provided answers.

- The possible answers are restricted and therefore facilitate comparison of answers between respondents.
- The answers are easier to analyze.
- It limits the possibility of respondents' providing double-barrelled answers.
- Participants can answer the items more quickly.

Disadvantages of closed ended questions is that a structured item cues the respondent with respect to possible answers and if categories are created that fail to allow the participant to indicate their feelings or beliefs accurately, the item is not very useful (McMillan & Schumacher, 2006:197). Participants may also develop an affinity for a certain response, for example, to mark every second block – this will cause the validity of the results to be questioned. In order to avoid this, test items had various degrees of difficulty.

The researcher made use of different types of closed ended questions in both questionnaires. The following response categories can be differentiated (Leedy & Ormrod, 2005:115):

- Multiple choice questions where the respondent's opinion was determined by him/her selecting the most appropriate choice according to his view (Questionnaire 1: Questions 12-13; Questionnaire 2: Questions 1 and 3);
- Yes/No questions were used to determine whether a participant agreed with a given statement or not (Questionnaire 1: Questions 3, 5-6, 14-15; Questionnaire 2: Questions 4-6, 9);
- Self-report questions with a list of scenarios which the respondent had to rate in terms of a fixed scale (Questionnaire 1: Questions 8-9; Questionnaire 2: Question 2).

In addition to closed ended questions, open ended questions were also included in both questionnaires (Questionnaire 1: Questions 1-2, 4, 7, 10-11, 16-17; Questionnaire 2: Questions 7-8). Open ended questions imply the least amount of control over the participants and provided them with the opportunity to give specific opinions or perceptions (McMillan & Schumacher, 2006:198).

4.6.1.2.6 Reliability and validity

Reliability is a term that refers to an instrument's ability to obtain the same results every time that it is performed and this will therefore lead to test-retest reliability (Delport, 2005:163). To obtain reliability to the highest possible degree the following steps were implemented:

- Each participant was contacted personally, telephonically or by e-mail to explain the purpose of the study and to obtain their consent to participate.
- A qualified audiologist performed all test procedures and real-ear measurements (Valente, 2006:33).
- Questions in the questionnaires were formulated in such a way as to eliminate ambiguity and to ensure clear and precise wording and instructions (Delport, 2005:163).

The **validity** of a measurement instrument refers the extent to which the instrument measures what it is supposed to measure (Leedy & Ormrod, 2004:28). According to Struwig and Stead (2001:136) it refers to the degree to which the research design is scientifically sound and appropriately conducted. To ensure validity as far as possible, the following steps were taken:

- The aims of the study were clearly and precisely formulated.
- A literature study was conducted to ensure that the questions included in the questionnaires were relevant to the validation of the hearing aid fitting process and music perception.
- The pilot study enhanced the validity of the verification measurements as it ensured the researcher's acquaintance and skills with the procedures that were followed assisted in the accurate interpretation of the results. In addition, the pilot study added to the validity of the questionnaires as it gave an indication of their effectiveness.
- The researcher included many participants in this study. The validity of a study increases with an increase in sample size (Leedy & Ormrod, 2004:28).
- Biographical data was obtained from each participant to account for the possibility of a person's musicality having an influence on the results of the MPT.

After the implementation of the above-mentioned steps, the questionnaires were valid regarding the following:

- **Content validity**: This is concerned with the representativeness of the content of the questionnaires and confirms that the questionnaires appropriately evaluate the behaviour and knowledge, in this case music perception, which it is supposed to (Delport, 2005:160). The use of relevant literature and discussions with professionals in the music industry concerning the design of the questionnaires ensured that content validity was obtained.
- **Face Validity**: Face validity concerns the superficial appearance of the questionnaires, and the way in which appropriate language was used in order to reach the aims (Delport, 2005:161). This is imperative when a questionnaire is used; Neuman (2003:284) clearly states that a 'professional appearance… and good layout improves accuracy and completeness and helps the questionnaire flow'. The questionnaires were professionally designed. A literature review and results obtained from the pilot study were integrated in the final selection of items and layout with the aim of guiding the participant in providing accurate and complete responses. Instructions and questions were also formulated in such a manner that it could easily be understood by all the participants. Furthermore the researcher presented the questionnaires to participants in a pilot study to determine whether or not it could be used as suitable research instruments in this study.
- **Construct validity**: Construct validity is concerned with the meaning of the questionnaires and thus involves validation of the instruments themselves as well as the theory underlying it (Delport, 2005:162). To increase the validity of the questionnaires the researcher tried to keep all instructions, language use and format as simple as possible and avoided ambiguous questions and statements. The researcher also took care to avoid biased questions.
- **Criterion validity**: This is determined when an instrument is compared to existing instruments that are valid (Bless & Higson-Smith, 2000:96). Due to the lack of valid evaluation material for the conduction of this study, the questionnaires used in this study were compiled by the researcher. These questionnaires could therefore not be compared to other questionnaires.

4.6.2 Apparatus

Apparatus used in this study consisted of audiometric and music equipment. The same apparatus was used in all the phases of the study and is discussed in Table 4-8.

Table 4-8: Data collection apparatus and procedures

Apparatus	Requisite	Justification	Procedure
		Audiometric Apparatus	
Heine Mini 2000 CE otoscope	The otoscope had new batteries to ensure optimum performance and was used with appropriate, sterilized specula.	The purpose was to evaluate the integrity of the external auditory meatus and tympanic membrane. It also enabled identification of possible abnormalities, strange objects or excessive wax which might have been present in the external ear canal or middle ear (Martin & Clark, 2000:234).	• The appropriate size speculum was selected for each participant. • The participant's ear was pulled up and backwards while performing the otoscopic examination to improve visibility (Katz, 2002:17). • The audiologist looked for any malformations in the external auditory meatus or tympanic membrane, signs of trauma or infection and ruled out any obstructions or excessive cerumen in the auditory meatus (Katz, 2002:17). • If any abnormalities were observed, the participant was referred to an ear, nose and throat specialist (Katz, 2002:17) and did not take part in any further testing until the problem was cleared.
GSI Tympstar immittance meter	The immittance meter was calibrated according to the requirements of the South African Buro of Standards (SABS) to ensure that reliable and correct results were obtained. The appropriate probes were selected for each participant to ensure a proper fit. All the probes were sterilized before use.	Tympanometry provides information regarding the ear canal volume, compliance (mobility) of the tympanic membrane as well as pressure within the middle ear (Martin & Clark, 2000:152). It is highly sensitive to conductive pathologies.	• Immittance testing only took place if the ear canal was clear of any occluding earwax or foreign objects as determined with the otoscopic examination (Martin & Clark, 2000:154). • Verbal instructions were given to the participant. • Tympanometry was conducted with a low-frequency probe tone of 220 Hz to 226 Hz (Martin & Clark, 2000:156). • The ear tip was pressed into the ear canal, a tight seal was obtained and the measurement was taken for both ears. • If no airtight seal could be obtained, resealing with a different sized tip took place. • Measurements of the pressure, volume and compliance were obtained. Values between 0.30 and 1.60 cm³ were considered the normal range for static compliance and ±100 daPa was representative of normal middle ear pressure (Martin & Clark, 2000:155). • If any abnormal results were obtained, the participant was referred to an ear, nose and throat specialist and did not take part in further testing until the problem was cleared.
GSI Audera oto-acoustic emission instrument	This instrument was calibrated according to the requirements of the SABS to ensure that reliable and correct results were obtained and all the probes were sterilized before use. The	Oto-acoustic emissions are sounds emanating from the cochlea that can be detected in the external auditory canal with probe-tube microphones (Martin & Clark, 2000:330). It allows for the study of cochlear function and will be un-recordable in the case of any	• Verbal instructions were given to the participant. • A probe containing a miniature loudspeaker to present the evoking stimulus and also a tiny microphone to pick up the emission and convert if from a sound into an electrical signal was placed in the ear canal (Martin & Clark, 2000:178) and measurements were obtained for both ears. • Acoustic control of the test environment as well as subject noise levels was taken into account. If subject noise levels are too high they may mask the emission, since the sensitive

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	appropriate probes were selected for each participant to ensure a proper fit.	conductive hearing loss. DPOAEs were measured for each ear to determine whether outer hair cell function was abnormal at frequencies corresponding to expected dead regions (Moore & Alcantara, 2001:271).	microphone used cannot differentiate one acoustic signal from another (Martin & Clark, 2000:178). • The presence of an OAE suggests there is very little or no conductive hearing loss caused by middle ear abnormality. It further suggests that responding frequency regions of the cochlea are normal or exhibit no more than a mild hearing loss and often compare favourable with voluntary audiometric results, provided that the hearing loss does not exceed 40 to 50 dB (Martin & Clark, 2000:177). It is also useful in differential diagnosis of cochlear versus retro-cochlear disorders (Martin & Clark, 2000:179).
GSI 61 two channel clinical audiometer	The audiometer was calibrated according to the requirements of the SABS to ensure that reliable and correct results were obtained. The test was conducted in a double walled soundproof test room.	This instrument was used to test peripheral hearing sensitivity for pure tones and speech and allows for a comparison of any person's hearing thresholds to that of an established norm (Martin & Clark, 2000:47). The purpose therefore is to specify the amount of a participant's hearing sensitivity at various frequencies and determine the degree of hearing loss (Martin & Clark, 2000:81).	• Verbal instructions were given to the participant. • Testing started in the better ear – this was determined by asking the patient. • Testing began at 1 kHz because this frequency is easily heard by most people and has high test-retest reliability. • The audiologist tested 1 kHz initially, tested lower frequencies (250 Hz and 500 Hz) in descending order, retested 1 kHz and then tested higher frequencies (2 kHz, 4 kHz and 8 kHz) in ascending order. • Information from all these frequencies were necessary in order to calculate the amount of frequency compression that was applied for each participant's individual hearing loss. • Mid-octave points were only tested when a difference of 20 dB or more was seen in the thresholds at adjacent octaves. • A pure tone was presented initially at 30 dB HL. If no response was obtained, the level was raised to 50 dB HL, introduced, and raised in 10 dB steps until a response was obtained or the limit of the audiometer was reached for the test frequency. • After a response was obtained, the level was lowered in 10 dB steps. When the tone was lowered below the patient's response level, it was raised in 5 dB steps until it was audible again, then lowered in 10 dB steps and raised in 5 dB steps until the 50% correct threshold response criterion has been met. The threshold is the lowest level at which the patient can correctly identify three out of a theoretical six tones. • Thresholds were obtained at each frequency, was recorded on an audiogram and the pure-tone average (PTA) (the average threshold levels for each ear at 500, 1000 and 2000 Hz) was calculated (Martin & Clark, 2000:83-84).
Sound-isolated room	The door of the room was solid and closed with a tight acoustic seal. The inside was covered with soft materials to help absorb sound and limit reverberations. The room had adequate ventilation and the lighting was incandescent (Martin & Clark, 2000:76-78).	Participants were tested in a sound-isolated room as it was acoustically isolated from the rest of the building in which it is housed and the noise in the room were kept below the level of masking that would cause a threshold shift in persons with normal hearing (Martin & Clark, 2000:76).	• The participant was seated properly inside the sound-isolated room – not to observe the clinician's movements during testing (Martin & Clark 2000:80).

Telephonic TDH-50 earphones	The earphones were sterilized before use for each participant.	Earphones were used for the presentation of pure tones. The earphones consist of a magnetic device that transduces the electrical translations supplied by the audiometer to a small diaphragm that vibrates according to the acoustic equivalents of frequency and intensity. Around the earphone was a rubber cushion that fitted over the ear (supra-aural). The movement of the earphone diaphragm generated the sound, which entered the ear directly, resulting in an air conduction signal (Martin & Clark, 2000:48).	• Earphones were placed properly with the headband directly over the top of the head. • All interfering hair was out of the way and earrings were removed when possible (Martin & Clark, 2000:82). • Eyeglasses were removed to avoid lifting the cushion of the earphone away from the ear. • The phones were positioned so that their diaphragms were aimed directly at the opening into the ear canal and the size of the headset re-adjusted for a tight fit (Martin & Clark, 2000:82). • The researcher checked for outer ear collapse which can cause an artificial conductive hearing loss which usually is characterized by poorer sensitivity in the higher frequencies, to avoid a misleading diagnosis (Martin & Clark, 2000:82).
Phonak Naida III Ultra Power (UP) digital behind-the-ear (BTE) hearing aids	Hearing aids were tested by a technician to ensure that they were in good working order, that there was no distortion and that the maximum output and gain were according to the specification sheets provided by the manufacturer. Listening checks were also performed with the use of a Stethoclip.	These instruments are digital and provide non-linear amplification in the form of multi-band compression. Furthermore, the hearing aid has an 80 dB of peak gain and 141 dB maximum output (Bohnert *et al.*, 2010:2). The hearing aid also has a unique combination of non-linear frequency compression (NFC), power processing and BassBoost to provide an extra-ordinary level of audibility and clarity.	• Every hearing aid was a behind-the-ear hearing aid connected by standard #13 tubing to a full shell acrylic ear mould with appropriate venting. • Hearing aids were connected to a HiPro NoaHlink (which was connected to a Mecer Celeron personal computer) with the programming cables from the hearing aid company. • Initial amplification values were calculated using the iPFG 2.6 software provided by the hearing aid company. • Hearing aids were fitted to the subject according to the DSL v5 method and adult targets were selected. • Besides the feedback canceller, all noise reduction systems were turned off, bass boost was not applied and all instruments were set to have an omni-directional microphone. The occlusion manager was adjusted to the desired subjective level and the start-up program was set to calm situations.
Audioscan Verifit verification instrument	This instrument was calibrated according to the requirements of the SABS to ensure that reliable and correct results were obtained. Probe tubes were sterilized before use.	The Audioscan Verifit was used to do real-ear measurements and verify the output from the hearing aid to ensure that prescriptive targets were matched within 3 dB/octave and to check whether distortion levels of the hearing aids were within acceptable levels (Ching, Hill & Dillon, 2008:469; Preves, 1994:369). It was further used to perform the specific REM (real-ear measurements), namely speech mapping, a real-ear measure to determine the SPL (sound pressure level) at the eardrum as well as the MPO (maximum power output) and gain of the hearing aid by using a speech input signal. The speech mapping is an	• Careful otoscopic examination was performed routinely every time before conduction of REM. This is considered an important first procedure as excessive cerumen and middle ear pathology might have a significant effect on probe-microphone measurements (Mueller, Hawkins & Northern, 1992:48) and also influence the ear canal's natural resonance characteristics that are important in the fitting of hearing aids. • Verbal instructions were given to the patient. • During measurements, placement specifications of the patient, as determined by the equipment's specifications were followed. The participant was seated in a chair one meter from the equipment, directly facing the loudspeaker of the equipment. • Probe microphone measures are the preferred method for verifying the real-ear performance of hearing aids (Valente, Bentler, Seewald, Tine & Van Vliet, 1998:6). The probe tube from the probe microphone was marked specifically according to the length of each participant's ear mould in order to ensure adequate depth in the ear canal after insertion of the mould into the ear canal. • To obtain the target speech mapping, the participant's

		important part of verification of the fitting of digital hearing aids since new technology centre on the amplification of speech (Mueller, 2005:22, Mueller, 2005:450).	audiometric data was entered into the Noah software as well as into the Audioscan Verifit hearing aid analyzer (Glista & Scollie, 2009b: 2). The DSL v.5 software (adult targets) was used to generate target values for gain and output to which the measured values were compared. The same DSL fitting parameters were selected for both the software and hearing aid analyzer. The DSL fitting algorithm only provides targets for frequencies up to 6 kHz, therefore the 6 kHz targets also were used to set the gain at 8 kHz (Stelmachowicz, Lewis, Choi & Hoover, 2007:484). • The first measurement involved the natural unaided response (resonance) of the ear without the hearing aid in place. This is referred to as the real-ear unaided response (REUR). A short burst of pink noise was presented at a level of 65 dB SPL and was stored as the unaided response. In the normal adult ear, the REUR has an amplitude peak of approximately 18 dB at 2.8 kHz (Katz, 2002:713). • Based on recent recommendations, REM of speech mapping measures were conducted because it utilized a speech input signal and therefore was more representative of the everyday situations faced by hearing aid users. Moore (2006:26) emphasizes this by stating 'the gains actually achieved for real-life signals such as speech and music differ considerably from the steady signals (of a probe microphone) such as tones and noise'. The recommended speech input level of 65 dB SPL was used to measure gain performance as 65 dB is considered equal to conversational level speech by evidence-based reviews (Mueller, 2005:459). • The fit to targets for soft (55 dB SPL), average (65 dB SPL) and loud (75 dB SPL) speech signals were evaluated with NFC inactive. • The MPO were verified with NFC inactive. • NFC was turned on. • The shape and gain of the hearing aid were verified using conventional measures of running speech with frequency compression at default settings. The researcher began by using the default setting provided in the manufacturer specific software, adjustments to increase or decrease the strength of the setting could be completed after considering further electro-acoustic measurement results and subjective feedback. • The fit to targets for soft (55 dB SPL), average (65 dB SPL) and loud (75 dB SPL) speech signals were evaluated. Fit-to-targets were only evaluated within the pass band of the device when NFC was active. The measurement becomes invalid beyond the upper bandwidth of the compressed signal where the hearing aid response rolls off. This is because gain is no longer applied to the region where the input signal has been compressed to a lower output signal. • Using a modulated speech signal, the verification at 65 dB was repeated and the researcher ensured that the curve above the cut off frequency has shifted to the left and was within audible range. • Measures of live voice productions of [s] and [sh] were used to assist in the evaluation of the audibility and/or separation of speech sounds. This was done by producing a sustained

			phoneme into the microphone of the connected hearing aid for S-REM. These measurements were done with and without NFC to illustrate the effects thereof and to evaluate the approximate audibility of different phonemes. • The MPO was verified with NFC active and results above the cut-off frequency were ignored. • A listening check was performed. Another aspect to take in consideration with NFC active is that the sound quality of speech may be different than with conventional sound processing. The phonemes [s] and [sh] may have been lowered in frequency, and the [s] may sound slightly like [sh] (a mild lisping quality). However, if the [s] sounds entirely like the [sh], fine tuning was done to reduce the strength of the NFC algorithm. The vowels and vocal tone may also be slightly altered, although each vowel should still be clearly identifiable (Glista *et al.*, 2008:5). When adverse sound quality effects were present, the researcher adjusted the NFC setting to make it weaker. • The evidence-based findings of Mueller (2005:459) and Fabry (2004:9) were taken as parameters to establish if measures met target values. Hence, REAR's of gain within 5 dB of the target gain value were accepted as on target.
Music equipment			
Sony D-FJ041 audio player	The researcher ensured beforehand that the audio player was in working order to avoid difficulties during testing.	The Music Perception Test (MPT) was presented with the audio player.	• The audio player was connected to the audiometer with the necessary cords provided from the manufacturers. • Stimuli of the MPTest were presented through the speakers in the audiometric booth according to the instructions of the test.
GSI Grason-Stadler speakers	The researcher ensured beforehand that the speakers were in good working order to ensure that the optimum sound quality is presented and to avoid distortion.	Stimuli of the MPT were presented through the external speakers at 75 dB SPL and hearing aid users were permitted to adjust the volume on their hearing aids for maximum comfort. Sound was presented at the same intensity for all hearing aid users, regardless of individual hearing thresholds. This was done as all participants had a moderate to severe hearing loss and therefore no drastic differences in audiometric thresholds were expected.	

4.6.3 <u>Material and apparatus for data analysis</u>

Responses were quantitatively coded and analyzed with computer software. Data was processed with the use of an HP Intel Core 2 3.0 GHz processor and Microsoft Windows Vista as well as Microsoft Office software.

4.7 PROCEDURE

Research was conducted using the following data collection, data recording and data analysis procedures:

4.7.1 <u>Data collection procedures</u>

The data collection process consisted of the pilot study and the main study. Participants in the main study were divided into four assessment groups which were assessed separately.

4.7.1.1 Pilot Study

A pilot study was conducted prior to the main study and comprised a small-scale administration of the main study and the use of the same procedures that are to be used in the main study (Struwig & Stead, 2001:135). The results of the pilot study were not used in the main study.

4.7.1.1.1 Purpose of the pilot study

The pilot study gave the researcher the opportunity to gain experience in the test procedures and enabled her to determine the time it will take to complete the test procedures (Maxwell & Satake, 2006:62). Furthermore, it enabled the researcher to test the accuracy and reliability of the MPT as a measuring instrument as well as to evaluate the validity and efficacy of the questionnaires (Maxwell & Satake, 2006:62). It also provided the opportunity to determine whether it was necessary to make changes to the MPT, instructions, test procedures and/or questionnaires. The pilot study served as a validation for the MPT and comprised stages two and three of the first phase of this study. The conduction of a pilot study improved the validity and accountability of the results of the main study. As mentioned before, validity of the MPT was ensured by several measures implemented in the development of the test, by obtaining criterion input and testing a target group. The description of validity implemented in the development of the test is provided in section 4.6.1.1.5 and will therefore not be addressed again. This section will focus on the description of validity by criterion input and the description of validity by testing a target group.

4.7.1.1.2 Participants

Two groups of participants took part in the pilot study: One group was included in the description of validity by criterion input and the other was included in the description of validity by testing a target group.

- *Participants included in the description of validity by criterion input*

Seven professionals in the audiology and music industry participated in this stage of the pilot study and were requested to complete the MPT evaluation sheet. These participants met the following criteria:

- Formal training in either Audiology and/or Music.
- Working actively at the time of the study as an Audiologist, Musician or Music teacher.
- Proficient and literate in English.

Audiologists were selected from the researcher's place of work while participants with music training were selected from a school to which the researcher had access. From the seven participants who took part in the peer review, four were Audiologists with an honours degree in Audiology, while the other three had a formal degree in music education. By selecting participants that were familiar to the researcher, communication between the researcher and the participants were enhanced and it was hoped that participants would be comfortable enough to provide honest feedback. This was also time effective and logistically convenient for the researcher.

- *Participants included in the description of validity by testing a target group*

In the first phase of this study fifteen normal hearing adults and four hearing aid users participated in Stage 2 and four adults with normal hearing as well as twenty hearing aid users in stage three. It was important to initially verify the MPT with a group of normal hearing listeners to ensure that the test was appropriate for administration with participants with a hearing loss (Looi *et al.*, 2008b:423).

The normal hearing adults who participated in the second and third stages of Phase 1 met the following criteria:

- Bilateral hearing thresholds for octave frequencies between 125 Hz and 8 kHz at 20 dB HL or better (Van Deun, Van Wieringen, Van den Bogaert, Scherf, Offeciers, Van de Heyning, Desloovere, Dhooge, Deggouj, De Raeve & Wouters, 2009:180).
- English language proficiency and literacy.
- No minimal musical background or experience level was required.

The mean age of the normal hearing adults that participated in Stage 2 and Stage 3 of Phase 1 was 39.5 years (range between 22 and 64 years). Only four of the adults included in Phase 2 had formal musical training while one adult included in Phase 3 indicated that prior musical training was received. The amount of musical training received by these adults ranged between two and seven years (Phase 2: 4 years, 2 years, 3 years and 2 years; Phase 3: 7 years).

Participants with normal hearing were selected from the researcher's place of work. This was done to enhance communication between the researcher and the participants. By selecting participants that were familiar to the researcher, the researcher hoped that participants would feel comfortable with giving honest feedback on the MPT and questionnaires. This enabled the researcher to make as many corrections as possible to the MPT, questionnaires and test procedures and thereby increased the reliability of the results. This process was also time effective and logistically easy for the researcher.

To demonstrate the feasibility of the MPT for clinical application, persons with hearing aids were recruited for stages two and three of Phase 1. The same selection criteria as described in Table 4-3 (Section 4.5.2) and selection procedures (4.5.3) were applicable to hearing aid users who participated in the pilot study. Table 4-9 and Table 4-10 provides the biographical information of the hearing aid users who participated in the pilot study. These data were obtained from the participants' files at the Audiology practice.

Table 4-9: Biographic information of participants with hearing aids included in Stage 2 of Phase 1

HEARING AID USERS INCLUDED IN STAGE 2 OF PHASE 1								
Biographic information	**P**	**Information**	**P**	**Information**	**P**	**Information**	**P**	**Information**
Age	1	64 years	2	64 years	3	43 years	4	60 years
Cause of hearing loss		Unknown		Noise-induced		Unknown		Unknown
Shape of hearing loss		R: Sloping L: Flat		R: Sloping L: Sloping		R: Flat L: Flat		R: Sloping L: Sloping
Pure tone average (PTA)		R: 75 dB L: 63 dB		R: 60 dB L: 60 dB		R: 63 dB L: 62 dB		R: 60 dB L: 60 dB
Oto-acoustic emissions		R: Absent L: Absent		R: Absent L: Absent		R: Absent L: Absent		R: Absent L: Absent
Current hearing aids		R: Extra 311 L: Extra 211		R: Extra 411 L: Extra 411		R: Una M AZ L: Una M AZ		R: Extra 33 L: Extra 33
Signal processing scheme		dSC		dSC		dWDRC		dSC
Time wearing hearing aids		4 years		5 years		10 years		9 years
Musical training received		None		None		3 years		1 year

The average age for hearing aid users in Stage 2 was 57.8 years (Range: 43 years to 64 years).

Table 4-10 provides the biographical information of the hearing aid users that participated in Stage 3. The average age of these participants was 55.9 years (Range: 33 years to 64 years). All of the participants had a post-lingual onset of hearing loss and were evaluated with their current hearing aids on an omni-directional microphone setting.

Table 4-10: Biographic information of participants with hearing aids included in Stage 3 of Phase 1

Partici-pant	Age	Cause of hearing loss	Shape of hearing loss	Pure tone average (PTA)	Oto:acoustic emissions (OAE's)	Current hearing aids	Signal processing scheme	Time wearing hearing aids	Musical training received
1	51 years	Unknown	R: Flat L: Flat	R: 70 dB L: 85 dB	Absent for both ears.	R: Eleva 33 L: Eleva 33	dSC	5 years	6 years
2	44 years	Unknown	R: Sloping L: Sloping	R: 55 dB L: 55 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Eleva 33 L: Eleva 33	dWDRC	6 years	4 years
3	34 years	Unknown	R: Sloping L: Sloping	R: 80 dB L: 80 dB	Absent for both ears.	R: Solo 411 L: Solo 411	dSC	10 years	none
4	33 years	Unknown	R: Flat L: Flat	R: 80 dB L: 70 dB	Absent for both ears.	R: Supero 411 L: Supero 411	dSC	8 years	none
5	64 years	Presbycusis	R: Sloping L: Sloping	R: 46 dB L: 44 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Extra 211 L: Extra 211	dWDRC	3 years	7 years
6	64 years	Presbycusis	R: Sloping L: Sloping	R: 50 dB L: 40 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Extra 311 L: Extra 311	dWDRC	5 years	none
7	63 years	Unknown	R: Sloping L: Sloping	R: 75 dB L: 40 dB	Absent for the right ear. Lowered at low frequencies and absent at high frequencies for left ear.	R: Una SP AZ L: Una SP AZ	dWDRC	9 years	none
8	61 years	Unknown	R: Flat L: Sloping	R: 85 dB L: 50 dB	Absent for the right ear. Lowered at low frequencies and absent at high frequencies for left ear.	R: Extra 411 L: Extra 211	dSC	5 years	none
9	63 years	Unknown	R: Flat L: Flat	R: 50 dB L: 45 dB	Absent for both ears.	R: Extra 311 L: Extra 311	dWDRC	2 years	1 year
10	61 years	Presbycusis	R: Sloping L: Sloping	R: 55 dB L: 60 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Extra 311 L: Extra 311	dSC	3 years	2 years
11	57 years	Unknown	R: Sloping L: Sloping	R: 45 dB L: 45 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Extra 311 L: Extra 311	dWDRC	4 years	none

12	60 years	Unknown	R: Sloping L: Sloping	R: 55 dB L: 55 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Solo prog L: Solo prog	dWDRC	3 years	2 years
13	63 years	Presbycusis	R: Sloping L: Sloping	R: 45 dB L: 40 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Solo prog L: Solo prog	dWDRC	4 years	1 year
14	53 years	Unknown	R: Sloping L: Sloping	R: 60 dB L: 40 dB	Absent for the right ear. Lowered at low frequencies and absent at high frequencies for the left ear.	R: Maxx 311 L: Maxx 211	dWDRC	5 years	1 year
15	60 years	Presbycusis	R: Sloping L: Sloping	R: 45 dB L: 40 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Una M AZ L: Una M AZ	dWDRC	2 years	1 year
16	55 years	Presbycusis	R: Sloping L: Sloping	R: 45 dB L: 45 dB	Lowered at low frequencies and absent at high frequencies for both ears.	R: Eleva 22 L: Eleva 22	dSC	5 years	4 years
17	48 years	Unknown	R: Sloping L: Sloping	R: 55 dB L: 55 dB	Absent for both ears.	R: Extra 311 L: Extra 311	dWDRC	4 years	none
18	64 years	Presbycusis	R: Sloping L: Sloping	R: 75 dB L: 80 dB	Absent for both ears.	R: Una M L: Una M	dWDRC	4 years	none
19	60 years	Unknown	R: Sloping L: Sloping	R: 85 dB L: 75 dB	Absent for both ears.	R: Extra 411 L: Extra 411	dWDRC	2 years	6 years
20	59 years	Unknown	R: Sloping L: Sloping	R: 50 dB L: 50 dB	Absent for both ears.	R: Una 22 AZ L: Una 22 AZ	dWDRC	3 years	none

4.7.1.1.3 Procedures for the conduction of the pilot study

Procedures for the conduction of the pilot study are described in two sections, namely procedures for the peer review and procedures for testing a target group.

- *Participants included in the description of validity by criterion input*

The following procedures were followed to obtain information from the peer review:

- Individual appointments were made with participants to describe the purpose of the study as well as the purpose of the evaluation of the MPT.
- After participants were informed of what was expected of them, they were subjected to the MPT.
- After completion of the MPT, participants were asked to complete the MPT evaluation sheet. Ample time was provided for the completion. Participants completed the evaluation sheet in the researcher's presence, before leaving the facility.
- After completion of the evaluation sheet, the procedures and content of the MPT and questionnaires were discussed with the participants. This was done in order to determine if it was relevant and whether any changes were needed.
- Participants were thanked for their time and participation.
- The data and comments were analyzed and interpreted to identify possible problem areas.
- The necessary changes were made to the test procedures, MPT and questionnaires.

- *Participants included in the description of validity by testing a target group*

Persons with normal hearing who participated in the pilot study were not fitted with the non-linear frequency compression hearing aids. The following procedures were followed for normal hearing participants:

- Individual appointments were made with participants to undergo a hearing evaluation to determine candidacy.

- The aim and procedures were explained to them. Participants were asked to provide comments regarding unclear or unnecessary procedures and questions and to comment on the time needed to complete the MPT as well as the questionnaires.
- After the hearing evaluation had been performed, the music perception testing took place.
- After completion of the MPT, participants were asked to complete the questionnaires. Participants were asked to complete both questionnaires even though not all questions were applicable because they did not wear hearing aids. In completing both questionnaires they could provide valuable feedback.
- Participants completed the questionnaires in the researcher's presence, before leaving the facility.
- After completion of the questionnaires, the procedures and content of the MPT and questionnaires were discussed with the participants. This was done in order to determine if it was relevant and whether any changes were needed.
- Participants were thanked for their time and participation.
- The data and comments were analyzed and interpreted to identify possible problem areas.
- The necessary changes were made to the test procedures, MPT and questionnaires.

Hearing aid users were evaluated according to the following procedures:

- Individual appointments were made with participants to undergo a hearing evaluation to determine candidacy.
- The aim and procedures were explained. Participants were asked to provide comments regarding unclear or unnecessary procedures and questions and to comment on the time needed to complete the MPT as well as the questionnaires.
- Prior to the hearing evaluation, each participant's current hearing aids were verified electro-acoustically to ensure that they were working properly and real-ear measurements were done to ensure that they were optimized to reflect current best practice (Auriemmo *et al.*, 2009:296; Flynn *et al.*, 2004:480).
- After the hearing evaluation, the MPT was administered to the participants who met the selection criteria.

- After completion of the MPT, participants were asked to complete both questionnaires. Participants completed the questionnaires in the researcher's presence, before leaving the facility.
- After completion of the questionnaires, the procedures and content of the MPT and questionnaires were discussed with the participants. This was done in order to determine if it was relevant and whether any changes were needed.
- Participants were thanked for their time and participation.
- The data and comments were analyzed and interpreted to identify possible problem areas.
- The necessary changes were made to the test procedures, MPT and questionnaires.

4.7.1.1.4 Results of the pilot study

The results of the pilot study were used to make the necessary changes to the test procedures, MPT and questionnaires. These results are discussed in detail in Chapter 5.

4.7.1.2 Main Study

Only persons who complied with the selection criteria in 3.5.2 were used as participants. In the procedures for data collection the following guidelines were strictly adhered to:

- *Phase 1: Presentation of the Music Perception Test*

Each participant was tested individually. Participants were seated in an audiometric test booth, facing the speaker at 45 degrees at a distance of approximately one meter. The stimuli were played on a Sony D-FJ041 audio player and presented via a Grason-Stadler GSI 61 two channel clinical audiometer to calibrated speakers (free field) simulating everyday listening experiences (Leal *et al.*, 2003:827). Conducting listening tests in a highly controlled environment, like an audiometric booth, has the advantage of higher sensitivity and accuracy of results (Zielinski *et al.*, 2008:431). The presentation level was 75 dB SPL for the calibration tone. The sound level was averaged at 75 dB SPL and hearing aid users were permitted to adjust the volume on their hearing aids for maximum comfort. Each participant was provided an answer sheet with a set of written instructions for each test section. All instructions were also presented via the speakers before the onset of each test. The test took roughly 55 minutes and featured simple instructions. The same equipment, physical set-up of the room, and instructions were used in Phase 1 (Stages 2 and 3) and in Phase 2 for the presentation of the test.

- *Phase 2: Objective testing*

In the light of technological advances clinical trials are typically conducted in an attempt to quantify any incremental improvement. The clinical trials are designed in such a way that recent technology is compared to a single current technology or fitting scheme (Bentler & Duve, 2000:625). In this phase the researcher compared non-linear frequency compression technology to conventional hearing instrument settings in order to quantify improvements in music perception. The following procedures were followed to obtain data:

- An in depth literature study was conducted to determine present theoretical perspectives and previous, related findings relevant for this study (Leedy & Ormrod, 2004:64).
- An appointment for the first visit was arranged telephonically or via e-mail with each participant for a time and date suitable to the participant.

Participants underwent the following procedures during their **first visit** to the practice:

- Each participant underwent a hearing evaluation to determine candidacy. This included performing an otoscopic examination, immittance testing, oto-acoustic emissions, pure tone audiometry and speech audiometry.
- Prior to fitting the prototype hearing aids, each participant's current hearing aids were verified with real-ear measurements to ensure that they were optimized to reflect the current best practice (Flynn *et al.*, 2004:480). This was also done in order to make accurate comparisons between the different technologies and to ensure that positive changes could be contributed to the NFC technology and not to optimization of the current hearing aids.
- If a participant's current hearing aids were not well fitted it could imply that the participant is not used to a certain amount of amplification; should it then be provided to him/her in order to

match targets, he/she may experience discomfort and this could lead to extra time for acclimatization. Therefore, for all participants who had poorly fitted hearing aids at the start of the study, extra time was provided to adjust to the optimized fitting without the NFC algorithm activated. In this way participants could get used to overall audibility and not to two things at once. After three weeks of acclimatization, the study commenced for these participants and the same procedures were followed as for all other participants.

- All the participants' ear moulds were evaluated to ensure a comfortable fit and provide a good seal without the presence of feedback (Skinner, Holden & Binzer, 1994:271).
- Participants were divided into four groups of ten persons each, where every participant was fitted with the NFC hearing aids. The groups were not simultaneously assessed and followed one another. Statistical procedures were implemented to randomly determine which participants would start with NFC active and which participants would start with this algorithm inactive. At the end of the study, half of the participants started with NFC activated and the other half with NFC not activated.
- The prototype hearing aids were fitted to the participants according to the Desired Sensation Level (DSL) method v5.0. The DSL fitting prescription were chosen over the NAL-NL1 fitting prescription because DSL prescribes more overall gain than NAL-NL1 for all hearing losses and provides more high-frequency emphasis than NAL-NL1 for sloping and severe losses (Scollie, 2006:10; Stelmachowicz *et al.*, 2002:319; Martin, 2001:88). DSL v5.0 targets for adults were used, given that all the participants were adults.
- Hearing aids were fitted to accurately match the prescribed targets provided by the DSL algorithm in order to ensure that they provide audibility at a comfortable level across speech frequencies (Ching *et al.*, 2008:461; Scollie & Seewald, 2001:121). For listening to music, all automatic sound features such as noise reduction and adaptive directionality were turned off. This was done to prevent these systems from interpreting the music as noise or feedback, which may affect the sound quality that participants perceive (Hockley, Bahlmann & Chasin, 2010:33). As all the participants had hearing aids for more than two years, all of them were used to amplification and therefore the hearing aids could be fitted on target for most of the participants. A few participants preferred the hearing aids slightly below target as they indicated that the sound was too loud when the hearing aids were fitted on target. It is important to take note of this fact as the level of audibility may affect the results.

- The performance of the hearing aids was verified with the use of the Audioscan Verifit. Real-ear measurements were performed and the average real-ear-to-coupler values for adults were used. The data obtained from these measurements were recorded in the form of a printout by the Audioscan Verifit.
- Because NFC compresses the high frequencies above the cut-off frequency into a lower frequency range, verification graphs will look different compared to conventional graphs (Phonak, 2009:1; Glista & Scollie, 2009a: par.2; McDermott, 2008:1). Measurement of high frequency gain or output warrant special consideration as a paradox emerges when measuring a hearing aid with NFC active (Scollie *et al.*, 2008:5). It looks as though the hearing aid has less high frequency gain or output, compared to measurements without NFC. This paradox occurs because the speech energy that is present in the higher frequencies has been lowered to the lower frequencies prior to the output from the hearing aid. Therefore, the apparent 'cut' that is shown at the cut-off frequency is not in fact a cut at all. Rather, the energy has been shifted downwards in frequency and now in all likelihood exists within the pass band of the device. This is not directly portrayed by the verification screen itself, but instead must be conceptually overlaid by the clinician when interpreting the measurement (Scollie *et al.*, 2008:5).
- A similar phenomenon occurs during the evaluation of maximum output (Scollie *et al.*, 2008:5). To determine whether the maximum power output measurement met target, only the fit-to-targets below the NFC cut-off frequency should be interpreted. Above the cut-off frequency the maximum output of the device apparently drops precipitously. Again, the role of the NFC should be interpreted in the measurements. The input energy entering the hearing aid at the cut-off frequency exits the hearing aid at a much lower frequency. The hearing aid analyzer is only measuring energy in the cut-off frequency region, and therefore does not register the actual level of output for the test signal. Particularly for narrowband tests such as pure tone sweeps or tests of maximum output using narrowband test signals, these effects are very strong, and do not give valid information above the cut-off frequency of the test signal (Scollie *et al.*, 2008:5). This can be accomplished by measuring the maximum power output with the NFC processor temporarily disabled. The observed maximum output in this condition has not ever been exceeded by frequency-lowered signals once the NFC processor was re-enabled. Essentially, this is analogous to setting the hearing aid to have appropriate outputs in the conventional condition prior to enabling the NFC processor. Therefore it seems that an acceptable maximum

output setting without NFC also provides acceptable output limiting when NFC is activated (Scollie *et al.*, 2008:6).

- Although technology may provide the mechanism for accurate feature classification among different acoustic environments, fine-tuning to meet the auditory needs and preferences of individuals require additional optimization (Fabry & Tchorz, 2005:36). Therefore adjustments were made according to the participant's preferences as it is important to recognize that a prescription is a simple rule that is best for an average listener and is unlikely to be perfect for an individual at all times (Fabry & Tchorz, 2005:36; Ching *et al.*, 2001:149). There are two adjustable parameters of frequency compression that are programmable: First there is the cut-off frequency which determines the start of the upper band and secondly, the compression ratio, which determine the amount of frequency compression applied to the upper band. The cut-off frequency and compression ratio were determined on an individual basis using the Phonak fitting software suggestions (Bagatto *et al.*, 2008: par. 6). For most patients the NFC algorithm was left on the default settings and was only changed if participants had complaints about the sound quality.
- The participants were asked to wear the hearing aids for a period of four weeks after which they returned to the practice. Four weeks were allocated for acclimatization because research with non-linear frequency compression indicates that benefits are best achieved with an acclimatization period of at least four weeks (Stuermann, 2009:2, Nyffeler, 2008b:24).
- The researcher orientated each participant with the new hearing aids to ensure that they were competent to handle the hearing aids.
- Participants were asked to complete Questionnaire 1 and hand it back to the researcher before leaving the practice.
- The researcher contacted all the participants after three days to determine whether they were satisfied with the hearing aids and if they needed any adjustment to the settings. If they experienced any problems they were encouraged to revisit the practice for fine tuning.

During participants' **second visit** to the practice the following procedures were conducted:

- After four weeks participants returned to the practice and the hearing aids were verified electro-acoustically to ensure that they were working properly (Auriemmo *et al.*, 2009:296).

- The MPT was performed with the hearing aid on its original settings that the participant acclimatized to previously.
- After the MPT was performed, the hearing aid settings for the four groups of participants were switched – participants that had their hearing aids with NFC active now had this algorithm deactivated and vice versa.
- Digital hearing aids have the capacity to gather, by themselves, information about the environments within which they functioned as well as about the time that they were used and thereby provide audiologists with informed advice (Gatehouse & Akeroyd, 2006:105). The researcher therefore first checked the data logging on the hearing aids to determine the average time used per day for each participant.
- Participants were asked to complete Questionnaire 2 and hand it to the researcher before leaving the practice.
- Again participants were contacted after three days to determine their satisfaction with the hearing aids and were encouraged to revisit the practice should any fine tuning be needed.

Procedures conducted during the **third visit** to the practice included:

- All participants returned to the practice after four weeks; at this visit the hearing aids were once again verified electro-acoustically to ensure proper functioning.
- The MPT was again performed.
- The researcher again read the data logging from the hearing aids to obtain information about the wearing time by each participant.
- Participants were asked to complete Questionnaire 2 and leave it with the researcher before departing.
- Participants who decided to buy the hearing aids (at a discounted price) kept them. Additional fine tuning was done if needed for example, adding additional programs to the hearing aids.
- Participants who did not buy the hearing aids returned them and were fitted with the hearing aids they used before the study.
- The results obtained from the different sub-tests of the MPT with NFC disabled and enabled were evaluated and compared for each participant. It was important to evaluate the performance of the hearing aids without NFC so that the effects of its electro-acoustic

characteristics could be partially separated from the effects of the frequency compression (McDermott *et al*, 1999:1326).

The validity of the data was maximized by using a randomized cross design with single blinding. In single blinding, only the subject or only the researcher know which group a subject is assigned to (Cox, 2005:428). During the course of the evaluation, the participant did not know whether the NFC algorithm was activated or not. This prevented any participant bias to influence the results (Bagatto *et al.*, 2008: par. 5). The use of single blinding prevents extremely positive results from participants due to the Hawthorne and Halo effects, where the subject responds more favourably because of their participation in a research experiment (Bentler & Duve, 2000:636). With the placebo effect the related explanation for the perceived subjective benefit is the assumption that new treatment or technology is better – the participant expect to perform better with the newer technology and therefore responds more favourably with this technology (Cox, 2005:428).

- *Phase 3: Questionnaires*

Questionnaire 1 was only completed once during the initial visit, while Questionnaire 2 were completed twice (once with NFC active and once with the algorithm inactive) on the second and third visit to the practice. Sufficient time was left for the completion of the questionnaires. Participants were asked to hand in the completed questionnaires at the end of each session, before leaving the practice.

A summary of the alternating assessment schedule of participants in the main study is presented Table 4-11.

Table 4-11: Alternating assessment schedule

	Visit 1		Visit 2		Visit 3	
Group 1 Group 3	Otoscopy Tympanometry Pure tone audiometry Speech audiometry Oto-acoustic emissions Hearing aid check and DSL verification Fitting with NFC hearing aid with non-linear frequency compression algorithm **active.** Completion of Questionnaire 1.	**ACCLIMATIZATION PERIOD 4 WEEKS**	Conduction of MPT with NFC **active**. Completion of Questionnaire 2. **Disable** non-linear frequency compression algorithm.	**ACCLIMATIZATION PERIOD 4 WEEKS**	Conduction of MPT with NFC **inactive**. Completion of Questionnaire 2.	**ANALYSIS OF RESULTS**
Group 2 Group 4	Otoscopy Tympanometry Pure tone audiometry Speech audiometry Oto-acoustic emissions Hearing aid check and DSL verification Fitting with NFC hearing aid with non-linear frequency compression **inactive.** Completion of Questionnaire 1.		Conduction of MPT with NFC **inactive**. Completion of Questionnaire 2. **Activate** non-linear frequency compression algorithm.		Conduction of MPT with NFC **active**. Completion of Questionnaire 2.	

- *Phase 4: Objective and subjective evaluation after extended period of use*

Participants who bought the hearing aids after the completion of Phase 3 were contacted again after a period of 12 weeks elapsed. They were asked to revisit the practice to determine whether use over time of NFC contributes to improved objective and subjective music perception. During this visit, they were asked to once again be subjected to the MPT with the NFC algorithm active as they used it during the time that elapsed. They were also asked to give their opinion on music perception after extended use of NFC by completing the second questionnaire again. The results obtained from these participants in Phase 2 of the study were compared with the results obtained in Phase 4. This was done in order to establish whether any additional music perception benefit was perceived with extended use of NFC and acclimatization.

4.7.2 Procedure for recording of data

Data was recorded for the MPT and the questionnaires as described below.

4.7.2.1 Data recording for Music Perception Test

Test scores from the MPT were directly written on the answer sheet of test. Each answer sheet was marked with the respondent number to ensure participants anonymity. All the answer sheets were controlled to ensure that it was completed in full before participants left the practice. The answer sheets were hand scored because some melodies have alternative titles and there are often multiple versions of lyrics. Furthermore, individual assessment of Sub-test 5, Sub-test 10 and Sub-test 11 was required because participants were only assessed in these sub-tests on items familiar to them and therefore the total for each of these sub-tests differed for all participants. The researcher transformed all the data from the answer sheets into a Microsoft Excel work sheet.

4.7.2.2 Data recording for questionnaires

Every questionnaire received a respondent number to ensure participants' anonymity. The respondent number was the same as the one provided for each participant on the MPT answer sheet. The numbers of the completed questionnaires ranged from 01 to 40 for each completed group of questionnaires (Questionnaire 1, Questionnaire 2 after second visit and Questionnaire 2 after third visit). All the questionnaires were controlled to ensure that it was completed in full. Furthermore a coding system was used for recording the responses to the questions and a code was created for every possible answer. In the case of 'Yes/No' questions, the code 1 was assigned to the answer 'Yes' and code 0 to 'No'. Where there were various answers to a question, a code were allocated to each answer for example codes 1 to 5 for each of the possible five answers. This method facilitated statistical analysis of the results.

4.7.3 Procedure for data analysis

Descriptive statistics was used during this study to classify, organize and summarize the observations in a manner convenient for numerically evaluating the attributes of the available data (McMillan & Schumacher, 2006:280). Statisticians were consulted throughout the course of the study and a combination of statistical software packages such as Excel and the Statistical Package for the Social Sciences (SPSS) were used. Results were converted to percentages and were described in terms of percentages. Descriptions included the central tendency of data (mean[15], median[16] and mode[17] values) as well as measures of variability (the range[18], the variance[19] and the standard deviation[20]) (McMillan & Schumacher, 2006:289-293). These analyses enabled the researcher to determine whether or not statistical significant relationships between the different parameters existed. Analyzed data were visually presented in the form of tables and graphs which included bar graphs, histograms and frequency distribution curves.

4.8 CONCLUSION

Music is a very important means of communication – some deafened people may feel quite depressed at its loss. Many persons with hearing aids attempt to listen to music, but with varying degrees of satisfaction. The effectiveness of rehabilitation can be measured by a music perception test (Medel Medical Electronics, 2006:1) like the one compiled for the purposes of this study. A good test of music perception should reliably differentiate many levels of ability in musically relevant tasks (Nimmons *et al.*, 2008:154). As music perception is highly complex, subjective impressions of music perception should also be collected with the use of questionnaires.

The method for conducting this research was systematically and comprehensively described in this chapter and conducted in such a manner that reliability and validity of the obtained data was

[15] The arithmetic average value of the data
[16] The midscore value of the data
[17] The most frequently occurring value of the data
[18] The difference between the highest value and the lowest value
[19] The mean of the squared deviation from the mean
[20] The square root of the variance

ensured. The method used also provided the researcher with the opportunity to gain maximum information in an accountable and ethical manner. The importance of optimal service delivery, including the provision of audiological services to persons with hearing aids who enjoy music, can not be ignored. From this perspective the aims for this study were formulated and the research method implemented.

4.9 SUMMARY

This chapter provided an in depth description of the procedures implemented during this research to realise the aims of the study. The aims and research design of this study were described, followed by the selection criteria for participation and a description of the participants included in this study. A description of the material and apparatus used for the collection, recording and analysis of data followed. Ethical issues as well as validity and reliability of this study were highlighted.

Chapter 5

RESULTS

Chapter aim: The aim of this chapter is to present the results of the empirical research along the lines of the specified sub-aims.

5.1 INTRODUCTION

Determining the influence of non-linear frequency compression on the perception of music by adults with a moderate to severe hearing loss required several data collection and analysis procedures. These procedures were conducted in different phases, as described in Chapter 4. The obtained results are described to correspond with the various sub-aims as represented in Figure 5-1.

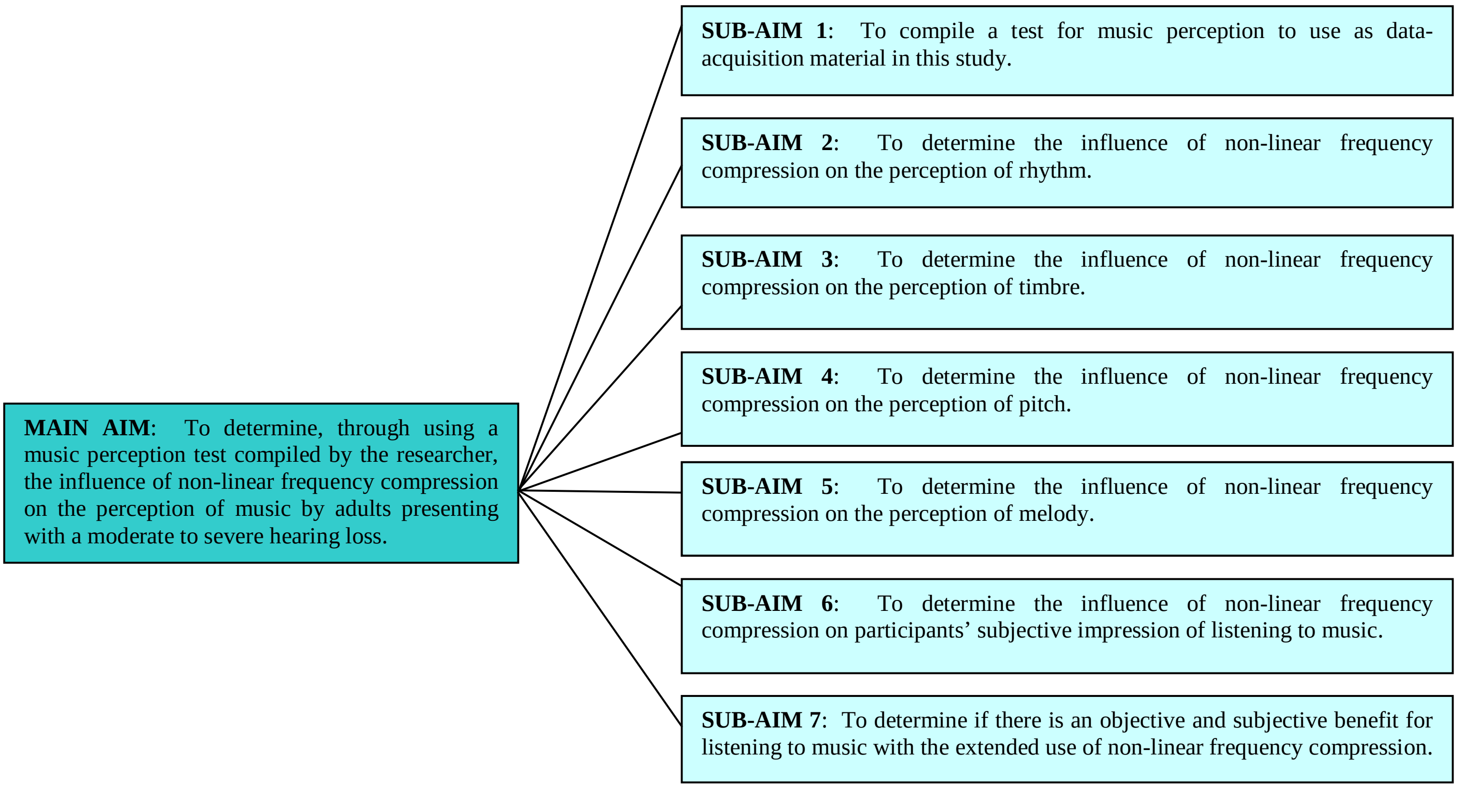

Figure 5-1: Presentation of results in correspondence with the sub-aims

The presentation of the results will be followed by answering the research question and the conclusion drawn from the results.

5.2 PRESENTATION OF THE RESULTS IN CORRESPONDENCE WITH THE SUB-AIMS

Results will be systematically presented in figures and tables in order to evaluate the data and point out significant as well as non-significant findings. To simplify the between-group (non-linear frequency compression (NFC) inactive versus active) comparisons for the scores and the analyses in this section, the scores for each participant's two runs of the test battery were averaged.

5.2.1 Background information of participants

A total of 40 adults with a moderate to severe hearing loss participated in Phase 2 and Phase 3 of the study. None of the participants discontinued participation and therefore the results of all 40 participants were available at the end of the data-collection phase. The selection criteria were met by all the participants. Background information of participants as obtained from Questionnaire 1 is displayed in Table 5-1.

Table 5-1: Background information of participants

Partici-pant number	Musical training received (in years)	Formal music qualification/s	Music instruments: plays currently /played before	Currently sings or ever sang in a choir or on social/professional gatherings	Feels that enjoyment of music has decreased with hearing problems	Removes hearing aid when listening to music
1	2 years	-	-	No	No	No
2	-	-	-	No	Yes	No
3	2 years	-	Piano	No	No	No
4	-	-	Guitar, piano	Yes	Yes	No
5	-	-	-	No	No	Yes
6	-	-	-	No	Yes	No
7	-	-	-	Yes	No	Yes
8	5 years	Unisa grade 3	Piano	No	Yes	No
9	-	-	-	Yes	Yes	No
10	-	-	-	Yes	Yes	No
11	7 years	Unisa grade 8	Piano	Yes	Yes	No
12	-	-	Trumpet	Yes	No	No
13	-	-	-	No	Yes	No
14	-	-	-	Yes	Yes	No
15	20 years	-	Piano	Yes	No	No
16	5 years	-	Piano	Yes	Yes	No
17	-	-	-	No	No	No
18	6 years	-	Flute, keyboard, guitar	Yes	No	Yes
19	14 years	Unisa grade 6	Piano	Yes	Yes	Yes
20	-	-	-	Yes	Yes	No
21	6 years	Unisa grade 5	Piano, violin	Yes	Yes	No
22	-	-	-	No	Yes	No
23	-	-	-	No	No	No
24	-	-	-	Yes	Yes	No
25	-	-	-	Yes	No	No
26	2 years	-	Piano	Yes	Yes	Yes
27	-	-	-	Yes	Yes	No
28	20 years	Unisa grade 8	Piano	No	No	No
29	-	-	Piano	Yes	No	No
30	1 year	-	Violin	No	Yes	No
31	1 year	-	Piano, harmonica	Yes	No	No
32	-	-	-	Yes	No	Yes
33	3 years	Unisa grade 4	Piano	No	Yes	No
34	-	-	-	Yes	Yes	Yes
35	10 years	-	Guitar, piano, harmonica	Yes	Yes	Yes
36	2 years	-	Accordion	No	Yes	No
37	-	-	-	No	Yes	No
38	-	-	-	No	Yes	No
39	-	-	Piano	Yes	No	No
40	-	-	-	Yes	No	No

Table 5-1 shows that 40% of the participants (n=16) received musical training, most of them for a period of five years or more (56% or 9 of 16). It is noteworthy that only 38% (6 of 16) of these participants had a formal musical qualification while the others indicated that they had musical lessons but never obtained a formal qualification or either had musical lessons in which they were taught to play by ear and not notation.

The musical instrument played by most of the participants was the piano, which was played by 37.5% of the participants (n=15), followed by the guitar and violin, each of which could be played by 5% of the participants (n=2). The trumpet, flute, keyboard, harmonica and accordion could each be played by one participant (2.5%). A total of 52.5% of the participants (n=21) indicated that they were not able to play any musical instrument or never played any musical instrument before. It is noteworthy that four participants who did not receive any musical training were able to play musical instruments (piano, guitar and trumpet). These four participants indicated that they taught themselves to play the musical instrument of their choice. Furthermore, most participants (57.5% or n=23) indicated that they currently sing or have previously sung in a choir or on social/professional gatherings.

The background information provided above assisted in the interpretation of the data obtained from the Music Perception Test (MPT) and second questionnaire.

5.2.2 Compilation of a music perception test to use for data collection (Sub-aim 1)

The purpose of the study was *to determine the influence of non-linear frequency compression on the perception of music by adults presenting with a moderate to severe hearing loss* through using a music perception test compiled by the researcher for the purposes of data collection. It is important to differentiate between the aim stipulated above and the possible aim of *developing a music perception test* in order to determine the influence of non-linear frequency compression on music perception for adults with a moderate to severe hearing loss, as this would result in two completely different studies requiring different methodological approaches.

Because the first sub-aim of this study was to compile a music perception test to use as material for data collection, the MPT was developed according to procedures described in Chapter 4. The pilot study was used to verify the use of the MPT on normal hearing listeners as well as on hearing aid users. Based on the results of the pilot study certain changes were made to the test; these changes are described below.

5.2.2.1 Results obtained from evaluation sheets

The perceptions of participants who were asked to complete the MPT evaluation sheet can be summarized as follows:

- Almost all the areas assessed with the evaluation sheet obtained a ranking of four or five by all participants and therefore one can conclude that they were satisfied with the appearance of the test, felt that the test were comprehensive for the assessment of music perception, found the difficulty rate of the stimuli to be balanced, were satisfied with the language used in the test and described the test as logically organized. Furthermore, they also indicated that sufficient time was provided for answering of the different questions and they were satisfied with the quality of the recordings of the test. None of them were of the opinion that the test was culturally inappropriate for South African people.
- The only aspect that got an average rating from some of the participants was the one regarding the clarity and preciseness of the instructions. In the comments section participants elevated this rating and indicated that they were slightly confused by the instructions on the pitch section of the test and therefore were not clear as to what was expected of them. Therefore, instructions were adapted to facilitate comprehension of this section.
- Other comments made by participants included that the test might be too long. Although the test was slightly shortened, too many items could not be eliminated as this would cause relevant information to be lost and therefore the test would no longer be comprehensive.

5.2.2.2 Results obtained from pilot testing of a target group

The participants in the target group for the pilot testing consisted of normal hearing listeners as well as hearing aid users. The results of the pilot testing can be summarized as follows:

- *Phase 1 Stage 2: Normal hearing participants*

Normal hearing participants obtained an average score of 88.8% for the rhythm section of the test with individual scores ranging between 70% and 100%. For the timbre section a group average of 74.1% were obtained while participants' scores ranged between 54% and 92%. An average score of 75.9% was obtained for the pitch section and 78.8% for the melody section. For the pitch section scores ranged between 50% and 100% while for the melody section scores ranged between 63% and 93%. These results are summarized in Table 5-2.

Table 5-2: Error rates and percentage 'correct' for the first version of the Music Perception Test presented to normal hearing participants (n=15)

Musical category	Test section	Maximum # responses (# items x n)	Group total errors	Group total correct (%)
Rhythm	1 Rhythm identification	12 x 15 = 180	13	167 (92.8%)
	2 Rhythm discrimination	12 x 15 = 180	14	166 (92.2%)
	3 Rhythm recognition	12 x 15 = 180	24	156 (86.7%)
	4 Rhythm perception	12 x 15 = 180	30	150 (83.3%)
Timbre	5a Single instrument identification	16 x 15 = 240 Actual max: 223*	43	180 (80.7%)
	5b Multiple instrument identification	16 x 15 =240 Actual max: 202*	47	155 (76.7%)
	6 Number of instruments	8 x 15 = 120	42	78 (65%)
Pitch	7 Pitch identification	12 x 15 = 180	20	160 (88.9%)
	8 Pitch discrimination	12 x 15 = 180	67	113 (62.8%)
Melody	9 Musicality perception	12 x 15 = 180	50	130 (72.2%)
	10 Melody identification	24 x 15 = 360 Actual max: 360*	99	261 (72.5%)
	11 Music-in-noise song identification	12 x 15 = 180 Actual max: 159*	13	146 (91.8%)

* Actual maximum for test differs from maximum possible responses as participants indicated with which items they were familiar and the final score was reported as a percentage of correct responses on the items with which the listener was familiar.

Table 5-2 indicates that participants performed best on the rhythm section of the MPT, with the highest average score obtained for the rhythm identification task. The worst performance was on the timbre section of the test while the lowest average group score was obtained for the pitch discrimination task. Three errors on any single item were defined on a practical basis as a high error rate for normal hearing listeners (20% of the sample). Spitzer *et al.*, (2008:60) indicated a high error rate when 15% of the sample got a certain item wrong. Sub-test 1 had only one item with a high error rate while two items in Sub-test 2 were found to have a high error rate, three items in Sub-test 3 and five items in Sub-test 4. In Sub-test 5 (part one) seven items were found to have a high error rate and in Sub-test 5 (part two), thirteen items. Sub-test 6 contained four items with a high error rate. Sub-test 7 contained two, and Sub-test 8 contained eleven of these items. Nine items in Sub-test 9, fourteen items in Sub-test 10 and one item in Sub-test 11 showed high error rates. All items with high error rates were either adapted or eliminated in constructing the adapted version of the MPT.

- *Phase 1 Stage 2: Participants with hearing aids*

Hearing aid users obtained an average score of 73.5% for the rhythm section, 51.2% for the timbre section, 67.7% for the pitch section and 40.2% for the melody section of the MPT. Individual scores ranged between 48% and 100% for the rhythm section, between 23% and 87% for the timbre section, between 48% and 100% for the pitch section and between 0% and 92% for the melody section. Theses results are summarized in Table 5-3.

Table 5-3: Error rates and percentage 'correct' for the first version of the Music Perception Test presented to participants with hearing aids (n=4)

Musical category	Test section	Maximum # responses (# items x n)	Group total errors	Group total correct (%)
Rhythm	1 Rhythm identification	12 x 4 = 48	6	42 (87.5%)
	2 Rhythm discrimination	12 x 4 = 48	12	36 (75.0%)
	3 Rhythm recognition	12 x 4 = 48	16	32 (66.7%)
	4 Rhythm perception	12 x 4 = 48	17	31 (64.6%)
Timbre	5a Single instrument identification	16 x 4 = 64 Actual max: 50*	27	23 (54.0%)
	5b Multiple instrument identification	16 x 4 =64 Actual max: 34*	15	19 (55.9%)
	6 Number of instruments	8 x 4 = 32	18	14 (43.8%)
Pitch	7 Pitch identification	12 x 4 = 48	11	37 (77.1%)
	8 Pitch discrimination	12 x 4 = 48	20	28 (58.3%)
Melody	9 Musicality perception	12 x 4 = 48	18	30 (62.5%)
	10 Melody identification	24 x 4 = 96 Actual max: 76*	32	44 (57.9%)
	11 Music-in-noise song identification	12 x 4 = 48 Actual max: 17*	16	1 (0.06%)

* Actual maximum for test differs from maximum possible responses as participants indicated with which items they were familiar and the final score was reported as a percentage of correct responses on the items with which the listener was familiar.

Table 5-3 shows that hearing aid users also performed best on the rhythm section of the MPT, and also with the highest average score obtained for the rhythm identification task. The worst performance was on the melody section, probably due to the extremely low scores obtained for the music-in-noise song identification task. Based on the results obtained in Stage two, the following major changes were made to the test:

- In order to shorten the test, most of the sections were reduced from twelve to ten items. The items eliminated in each section were those that were found to have the highest error rates. By shortening the MPT the reliability of the test was increased because the probability of poor results due to the duration of concentration and fatigue were reduced.
- For Sub-test 5 (part two) the difficulty of the test items was reduced. Most of the items consisted of three musical instruments playing together. Participants were unable to identify three instruments correctly, but could identify one or two instruments playing in an ensemble. Stimuli were therefore changed so that most items included only two instruments playing together, with only a few items being more difficult with a combination of three instruments.
- The same principle was followed in Sub-test 6. The rate of difficulty was also reduced to fewer musical instruments playing together, since the items with high error rates were those where four or five instruments were combined.
- A decrease in participants' scores was visible for Sub-test 8. This was not found to be related to difficulty of the test items but rather to unclear instructions. These items were therefore left unchanged with only the two items with the highest error rates being removed. Focus was placed on changing the instructions to eliminate misunderstanding.
- The analysis of the results of Sub-test 10 showed that most participants were confused by two of the items which sounded very similar. These items were 'Baa Baa Black Sheep' and 'Twinkle, Twinkle Little Star' of which the first few notes are almost identical. By only confusing these two melodies, the percentage of success on this task dropped by 16.7% (two melodies each being presented twice). It was therefore decided to remove one of these melodies to avoid unnecessary confusion. The item with the highest error rate was also removed, thereby reducing the number of test items to 20 instead of 24.
- Sub-test 11 posed no problems with the normal hearing participants but all of the hearing aid users obtained no score for this test. The hearing aid users all complained that the

background noise was too loud and that they were unable to hear the melody. For this reason the stimuli were changed by reducing the intensity of the noise compared to that of the melody. Furthermore, the two items with the highest error rates were removed, reducing the number of items to ten.

- Technical adjustments and language editing were done to improve the MPT and reduce confusion.

The adapted version (Appendix H) of the MPT consisted of the same sections as the first version (Appendix G), but most of the sections were shorter in order to reduce the length of the test. The adapted version was constructed with a total of 140 items (Sub-test 1, 2, 3, 4, 7, 8, 9, 11 = 10 items each, Sub-test 5 (part one) = 16 items, Sub-test 5 (part two) = 16 items, Sub-test 6 = 8 items and Sub-test 10 = 20 items). A marking sheet with all the answers of the adapted version of the test is provided in Appendix F.

In Stage 3 of Phase 1 the adapted version of the MPT was again presented to adults with normal hearing (n=4) and with hearing aids (n=20). Scores for the different sections of the test improved on presentation to the adults with normal hearing when compared to the results of normal hearing listeners in stage two, as can be seen in Table 5-4. Normal hearing participants obtained an average score of 93.8% (ranging from 80% - 100%) for the rhythm section and 83% (ranging from 66% - 100%) for the timbre section. An average score of 86.3% (ranging from 70% - 100%) was obtained for the pitch and 88.2% (ranging from 68% - 100%) for the melody section.

Table 5-4: Error rates and percentage 'correct' for the adapted version of the Music Perception Test presented to normal hearing listeners (n=4)

Musical category	Test section	Maximum # responses (# items x n)	Group total errors	Group total correct (%)
Rhythm	1 Rhythm identification	10 x 4 = 40	2	38 (95.0%)
	2 Rhythm discrimination	10 x 4 = 40	1	39 (97.5%)
	3 Rhythm recognition	10 x 4 = 40	3	37 (92.5%)
	4 Rhythm perception	10 x 4 = 40	4	36 (90.0%)
Timbre	5a Single instrument identification	16 x 4 = 64 Actual max: 60	8	52 (86.7%)
	5b Multiple instrument identification	16 x 4 =64 Actual max: 53*	10	43 (81.1%)
	6 Number of instruments	8 x 4 = 32	6	26 (81.3%)
Pitch	7 Pitch identification	10 x 4 = 40	3	37 (92.5%)
	8 Pitch discrimination	10 x 4 = 40	8	32 (80.0%)
Melody	9 Musicality perception	10 x 4 = 40	7	33 (82.5%)
	10 Melody identification	20 x 4 = 80 Actual max: 80*	8	72 (90.0%)
	11 Music-in-noise song identification	10 x 4 = 40 Actual max: 38*	3	35 (92.1%)

* Actual maximum for test differs from maximum possible responses as participants indicated with which items they were familiar and the final score was reported as a percentage of correct responses on the items with which the listener was familiar.

Once again the best average score was obtained for the rhythm section of the test while the lowest average score was obtained for the timbre section. The task with the highest score was the rhythm discrimination task whereas the pitch discrimination task obtained the lowest average score.

The results of Stage 3, in which the MPT was administered to hearing aid users, are summarized in Table 5-5. In this phase, hearing aid users obtained an average score of 75.5% (ranging from 60% - 100%) for the rhythm section, 62.3% (ranging from 46% to 94%) for the timbre section, 70.8% (ranging from 60% - 100%) for the pitch section and 61.9% (ranging from 39% - 100%) for the melody section of the MPT.

Table 5-5: Error rates and percent 'correct' for the adapted version of the Music Perception Test presented to participants with hearing aids (n=20).

Musical category	Test section	Maximum # responses (# items x n)	Group total errors	Group total correct (%)
Rhythm	1 Rhythm identification	10 x 20 = 200	31	169 (84.5%)
	2 Rhythm discrimination	10 x 20 = 200	46	154 (77.0%)
	3 Rhythm recognition	10 x 20 = 200	43	157 (78.5%)
	4 Rhythm perception	10 x 20 = 200	76	124 (62.0%)
Timbre	5a Single instrument identification	16 x 20 = 320 Actual max: 196*	80	116 (59.2%)
	5b Multiple instrument identification	16 x 20 =320 Actual max: 119*	55	64 (53.8%)
	6 Number of instruments	8 x 20 = 160	42	118 (74.0%)
Pitch	7 Pitch identification	10 x 20 = 200	52	148 (74.0%)
	8 Pitch discrimination	10 x 20 = 200	65	135 (67.5%)
Melody	9 Musicality perception	10 x 20 = 200	91	109 (54.5%)
	10 Melody identification	20 x 20 = 400 Actual max: 328*	105	223 (68.0%)
	11 Music-in-noise song identification	10 x 20 = 200 Actual max: 87*	32	55 (63.2%)

* Actual maximum for test differs from maximum possible responses as participants indicated with which items they were familiar and the final score was reported as a percentage of correct responses on the items with which the listener was familiar.

From Table 5-5 it is clear that hearing aid users performed the best on the rhythm section of the test and obtained the highest score for the rhythm identification task. These listeners again obtained the lowest average score for the timbre section with the identification of multiple instruments being the most difficult task.

With a bigger, heterogeneous group of hearing aid users who were subjected to the adapted version of the MPT, a few observations were made. Firstly, the entire sample was able to perform all the different sub-tests of the MPT. None of the participants was confused by the tasks or unable to participate. Table 5-5 shows that all participants found Sub-test 1, Sub-test 2, Sub-test 3 and Sub-test 4 relatively easy; they performed fairly well on these tasks, scoring an average of 60% or more. Results for Sub-test 5 (single and multiple instruments) were somewhat different and are presented in Figures 5-2 and 5-3.

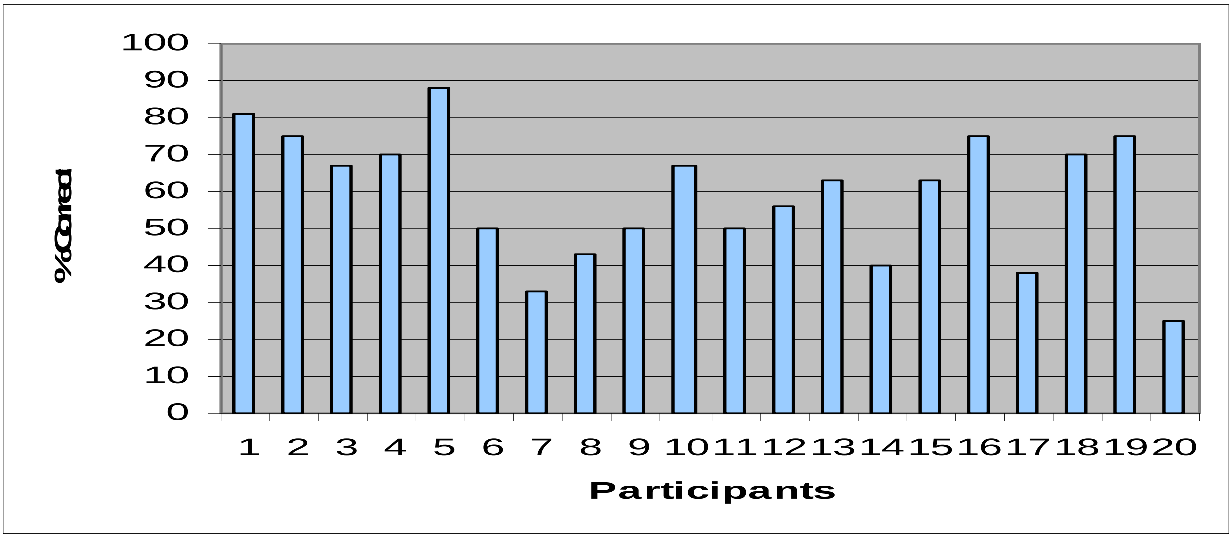

Figure 5-2: Participants' performance on the single instrument identification task (Sub-test 5 part one)

As demonstrated in Figure 5-2, just over half of the participants (n=11) obtained a score of 60% or more for this task while the other nine participants' scores ranged from 25% - 56%. It was noted that participants who performed better on this task were those that indicated that they were able to play one or more musical instruments or had formal musical training. Figure 5-3 displays participants' performance on the multiple instrument identification task.

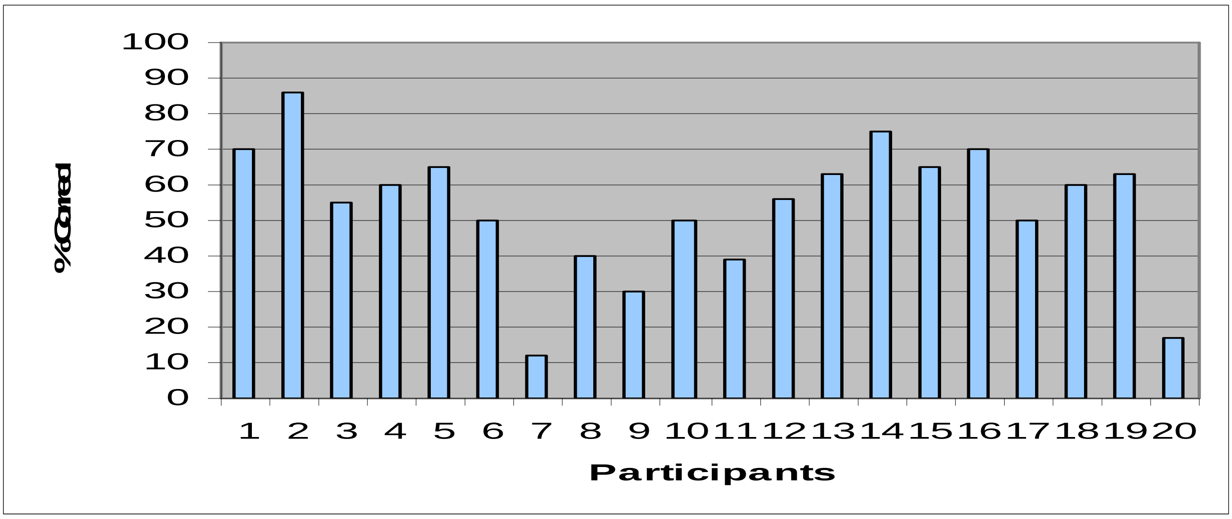

Figure 5-3: Participants' performance on the multiple instrument identification task (Sub-test 5 part two)

The scores displayed in Figure 5-3 indicate that participants obtained much lower scores for this task than for the previous one. This outcome was expected because the combination of instruments that were included, added to the difficulty of the task. A total of 65% (n=13) of the participants obtained lower scores for the multiple instrument identification task compared to the single instrument identification task, with only 20% (n=4) of the participants showing improved scores on the more challenging task. For one participant the improvement was very slight (only 2%), but for the remaining three participants an improvement of respectively 11%, 35% and 12% were seen. This improvement was not expected. An interesting aspect was that when asked what, in their opinion contributed to their superior performance, all three of them replied that they regularly listened to classical music and therefore found the identification of instruments presented in an ensemble less difficult. This phenomenon may probably be explained by the fact that classical compositions consist of complex harmonic progressions, intricate rhythms and timbre blends (Gfeller *et al.*, 2005:241) and merits more detailed investigation.

Results obtained on Sub-test 6, Sub-test 7, Sub-test 8, Sub-test 10 and Sub-test 11 were all relatively good with an average score for all of these tasks of 60% or above. The range of scores for the tests mentioned above can be summarized as follows:

Sub-test 6 – Number of instruments	29% - 100%
Sub-test 7 – Pitch identification	50% - 100%
Sub-test 8 – Pitch discrimination	50% - 100%
Sub-test 10 – Melody identification	30% - 90%
Sub-test 11 – Music-in-noise song identification	0% - 100%

Participants obtained a lower average score for the musicality perception task. The pertaining data is displayed in Figure 5-4.

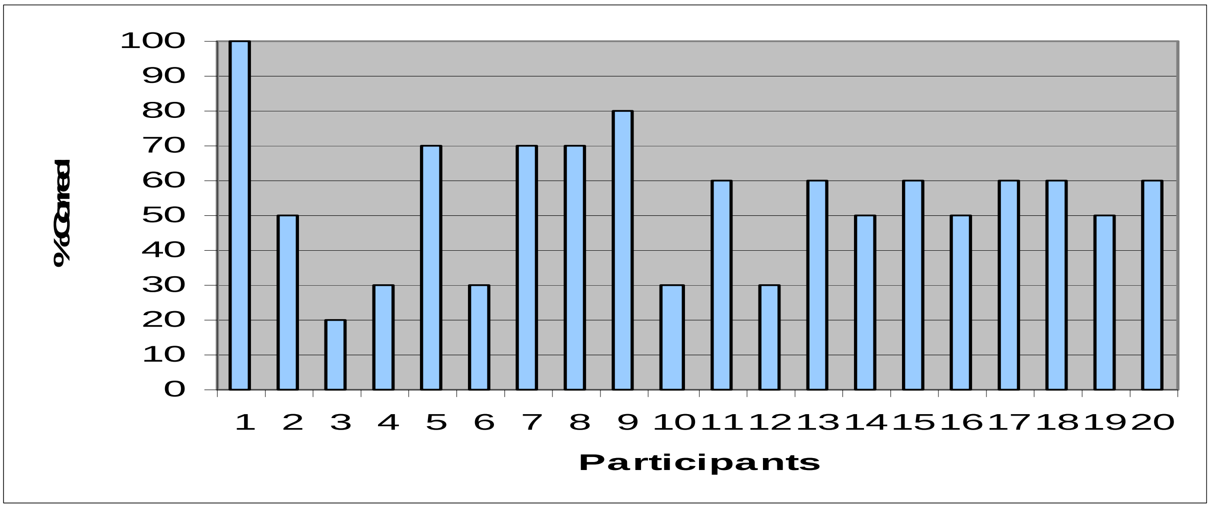

Figure 5-4: Participants' performance on the musicality perception task (Sub-test 9)

From Figure 5-4 it seems that participants found the musicality perception task challenging; they obtained an average score of only 54.5% for this task. This task again has a correlation with musicality and therefore explains the tendency of participants with previous musical training to perform better than those with no musical training.

Various measures were taken to increase the validity and reliability of the MPT, as were explained in Chapter 4. In order to further increase the validity of this test Cronbach's alpha determinations were done. These determinations are applied to determine the internal consistency of a particular test by determining the degree of relatedness among the items on a particular test by splitting the test into two or more parts and determining the correlation between the scores (Maxwell & Satake, 2006:121). The Cronbach's alpha determinations were run on all the sub-tests of the MPT with the purpose to indicate whether the different items grouped together in a sub-test belonged to that specific sub-test. This procedure could further give an indication of which item (s) should be eliminated from the group to increase the validity of that specific group. After discussions with the statistician it was decided to ignore the results of the Cronbach's alpha determinations because this analysis rendered obscure results. This could be attributed to the fact that the data of the MPT was not really appropriate for a Cronbach's alpha determination as this determination usually works with scale values which are more than simply two values. In many cases the answers of the MPT are restricted to only one or two values, for example Sub-test 2 (yes/no), Sub-test 3 (waltz/march), Sub-test 5 (name of a music instrument), Sub-test 6 (one numerical number), Sub-test 7 (high/low), Sub-test 8 (yes/no), Sub-test 10 (name of one melody) and Sub-test 11 (name of one soundtrack). Furthermore, the high rate of variability in participants' results also contributed to the obscure results obtained with the Cronbach's alpha determinations.

The results obtained with the adapted version of the MPT for hearing aid users that participated in Phase 2 are described in detail in the sections to follow.

5.2.3 The influence of non-linear frequency compression on the perception of rhythm (Sub-aim 2)

The second sub-aim of the study was to establish the influence of non-linear frequency compression on the perception of rhythm. The results include responses to items from Section A of the MPT and specifically Sub-test 1 (Rhythm identification), Sub-test 2 (Rhythm discrimination), Sub-test 3 (Rhythm recognition) and Sub-test 4 (Rhythm perception).

The first sub-test of the MPT evaluated participants' **rhythm identification** abilities. In this task participants were presented with five groups consisting of six pulse tones, spaced 369 ms apart from one another except for two pulses which were grouped together with a space of 32 ms in between. Five different patterns were used, each differentiated by the position of the short-inter-pulse interval. Participants were asked to identify which group they heard. The results are displayed in Figure 5-5.

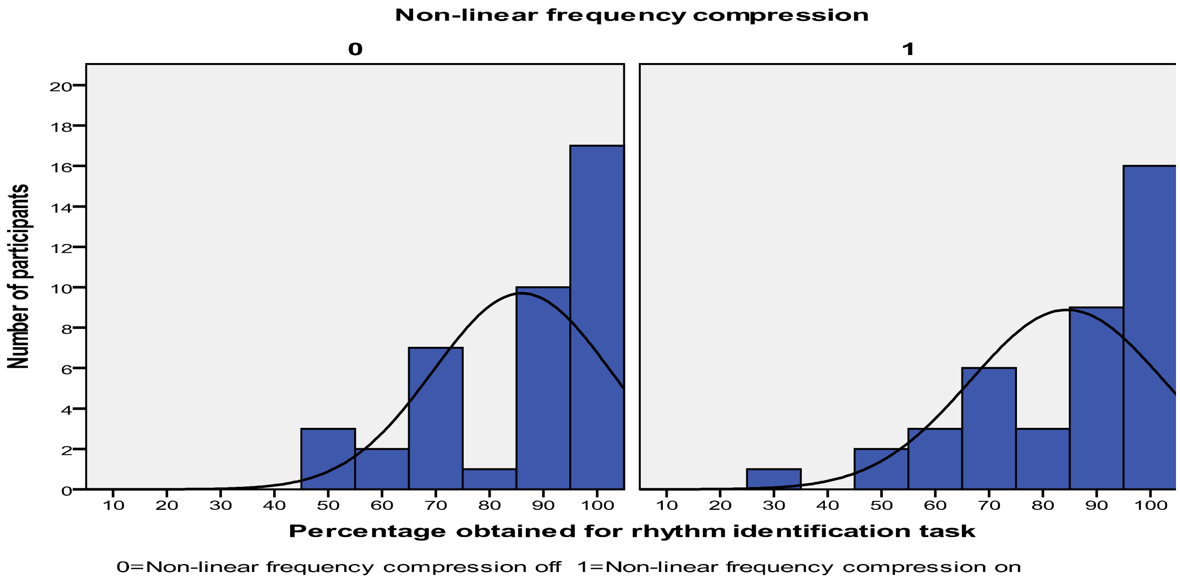

Figure 5-5: Participants' scores for rhythm identification (Sub-test 1) with non-linear frequency compression off versus non-linear frequency compression on

From Figure 5-5 it is clear that 35% of the participants (n=14) obtained the exact same score for the rhythm identification task with NFC off versus NFC on. Another 37.5% (n=15) showed a lower score with NFC on, while 27.5% of the participants (n=11) showed an increase in their scores with the NFC algorithm activated. In the cases where there were a difference in the scores obtained with NFC off versus NFC on, these differences were very small. Mostly participants' scores decreased or increased with only 10% to 20% (equivalent to one or two answers in the sub-test), with only one participant who showed a decrease of 40% when NFC was activated.

The next task for rhythm assessment was a **rhythm discrimination** task. In this task participants were presented with different pairs of rhythms and had to indicate whether the rhythm patterns in a given pair were the same or different. Results obtained from this sub-test are displayed in Figure 5-6.

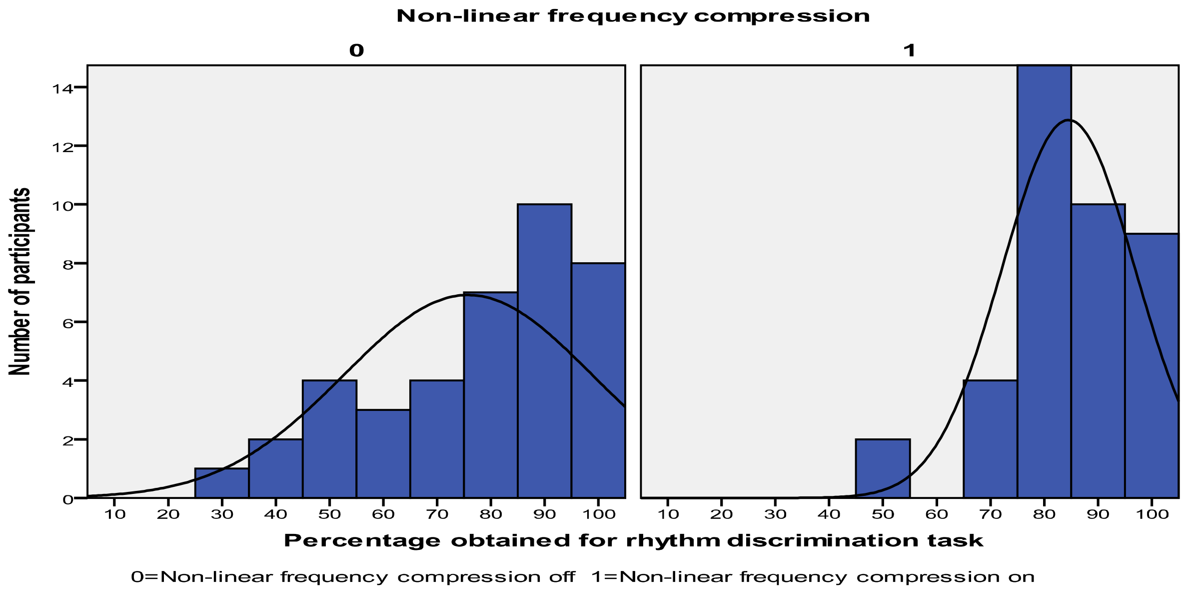

Figure 5-6: Participants' scores for rhythm discrimination (Sub-test 2) with non-linear frequency compression off versus non-linear frequency compression on

Again, almost a third of the participants (32.5% or n=13) obtained the same score for this task with the NFC algorithm on both settings. Only 22.5% of the participants (n=9) showed decreased scores with the activation of NFC, while 45% of the participants' (n=18) scores increased when NFC was activated. In the cases where scores decreased, differences were very small; only one participant's score decreased with more than 10% (equivalent to more than one answer in the sub-test). A slightly bigger difference was seen for participants whose scores increased with the activation of NFC where 44.4% (8 of 18) showed a score increase of 30% or more.

Sub-test 3 of the MPT tested **rhythm recognition**. In this sub-test, participants were presented with various melodies which were rhythmically structured as either a waltz (melodic pattern in triple meter) or a march (melodic pattern in duple meter) and they had to indicate whether the melody they heard was representative of a waltz or a march. Figure 5-7 presents the results of this sub-test.

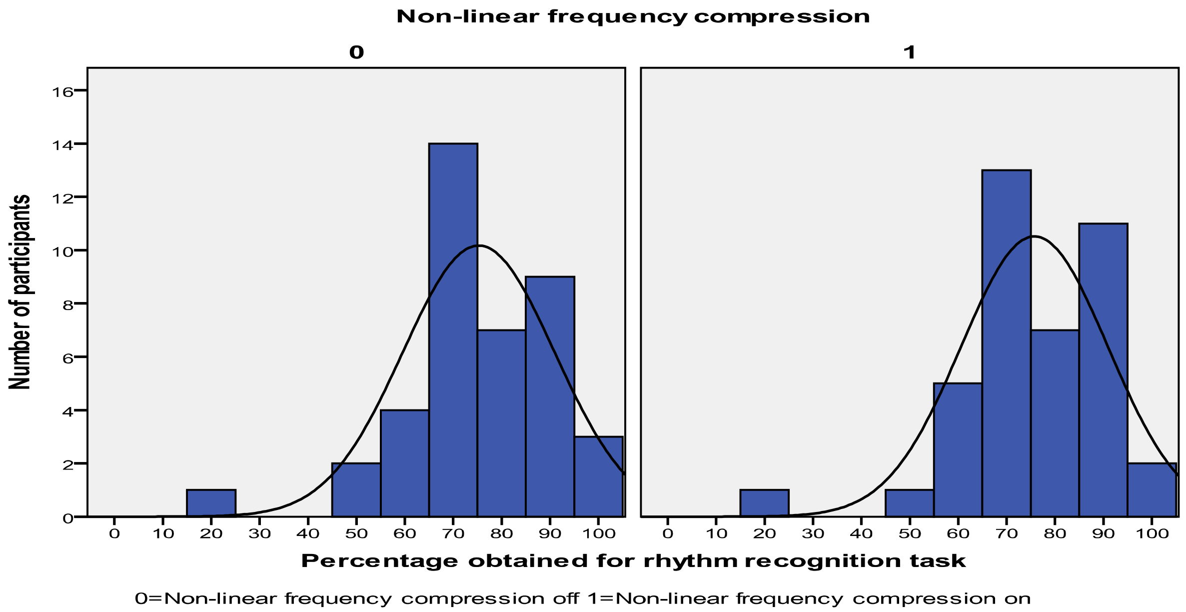

Figure 5-7: Participants' scores for rhythm recognition (Sub-test 3) with non-linear frequency compression off versus non-linear frequency compression on

From Figure 5-7 one can conclude that 32.5% of the participants (n=13) showed a decrease in their scores with the activation of NFC, while for 42.5% of the participants (n=17) the activation of this algorithm resulted in better performance. Again the differences in performance were very small, with only two participants whose scores decreased with more than 30%; one participant's score increased with more than 30%.

The final sub-test in the rhythm section assessed **rhythm perception** which focused on the discrimination of serial temporal patterns (Rammsayer & Altenmuller, 2006:38). In this sub-test, participants were presented with pairs of melodic sequences. In each pair, either the first or the second melody was played rhythmically out of time and was therefore not musically rhythmical. Participants were asked to indicate which melodic sequence in each pair was played rhythmically in time. The results are displayed in Figure 5-8.

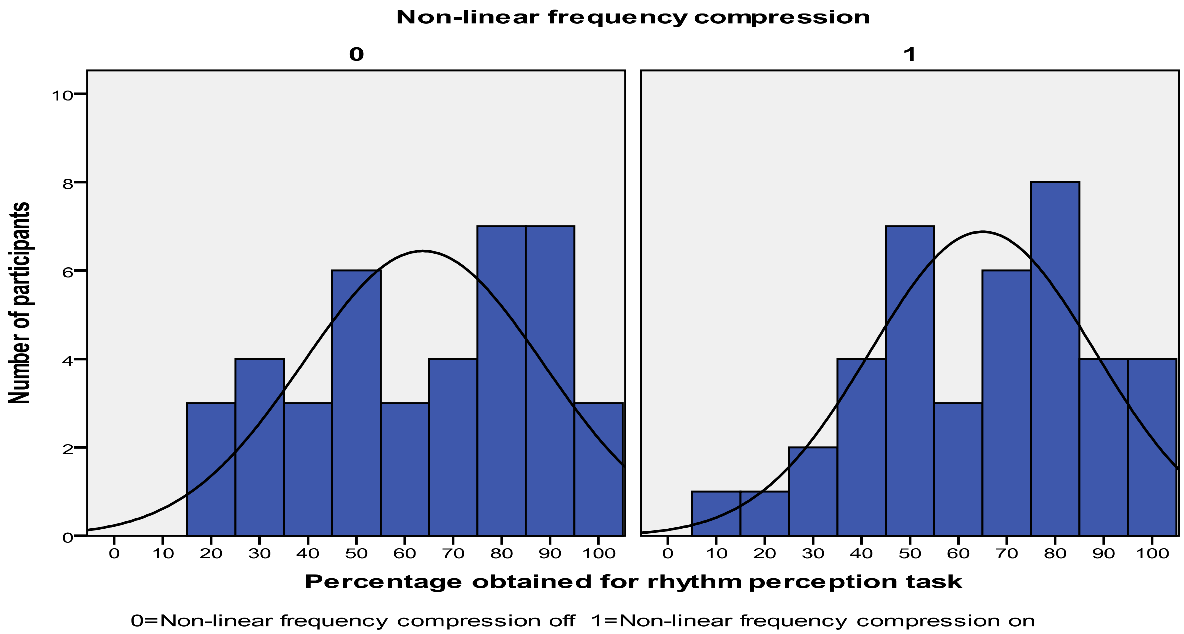

Figure 5-8: Participants' scores for rhythm perception (Sub-test 4) with non-linear frequency compression off versus non-linear frequency compression on

Figure 5-8 illustrates that 25% (n=10) of the participants obtained the same score for the rhythm perception task on both NFC settings. For 40% of participants (n=16) the activation of NFC resulted in a decrease in their scores, while 35% (n=14) had a more positive outcome when this algorithm was activated. In contrast to the other rhythm sub-tests, the differences in participants' scores for this test was much bigger, with six participants scoring lower by 30% or more and another six participants showing scores that increased with 30% or more with the activation of NFC.

The scores for the four different rhythm sub-tests were combined to determine whether there was an overall difference in participants' performance on **rhythm** with the activation of NFC. These results are displayed in Figure 5-9.

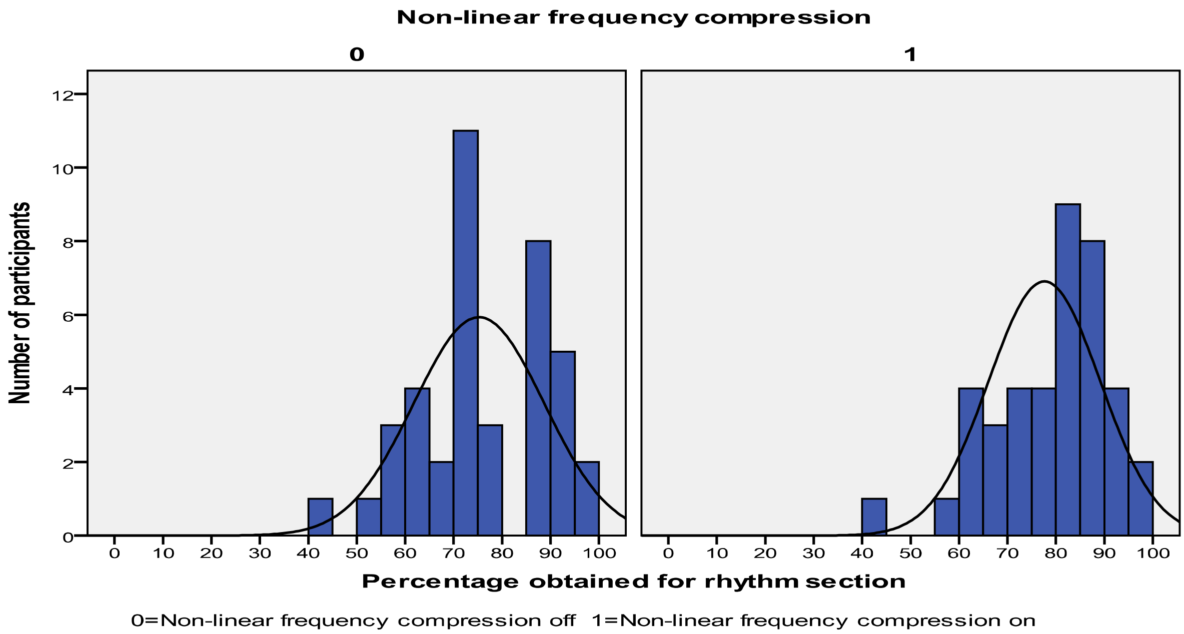

Figure 5-9: Participants' scores for the rhythm section (Section 1) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

In total, 35% of the participants (n=14) obtained a lower score for the perception of rhythm with the activation of NFC, while 50% of the participants (n=20) were better able to perceive rhythm when this algorithm was activated. It seems that the decrease in performance was less than the improvement in performance as none of the participants' scores decreased with more than 10%, while almost half of the participants (9 of 20) showed a score increase of 10% to 23%. For 15% of the participants (n=6) the activation of the NFC algorithm had no effect on performance.

Inferential statistical analyses were performed on the results described above, the aiming to statistically verify whether participants performed better with NFC active compared to this algorithm being inactive on a five percent level of significance. The statistical test used was the paired t-test which compares the differences between two means of dependent samples for paired observations (Maxwell & Satake, 2006:334). This was specifically appropriate for the data of the current study because it allowed the researcher to evaluate hypotheses resulting from the same group of adults being evaluated twice as each adult was assessed with NFC active and inactive. Each subject was therefore being used as its own control which is characteristic of this pairing design (Maxwell & Satake, 2006:333). Table 5-6 presents the summarized descriptive inferential statistical values for the different rhythm sub-tests as presented in Figures 5-5 to 5-9.

Table 5-6: Descriptive inferential statistical values for the perception of rhythm with non-linear frequency compression off versus non-linear frequency compression on

DESCRIPTIVE		NON-LINEAR FREQUENCY COMPRESSION OFF	NON-LINEAR FREQUENCY COMPRESSION ON
Rhythm identification (Sub-test 1)	Minimum	50%	30%
	Maximum	100%	100%
	Mean	86%	84.5%
	Standard deviation	16.46%	17.97%
	p-value	0.37	
Rhythm discrimination (Sub-test 2)	Minimum	0%	50%
	Maximum	100%	100%
	Mean	75.8%	84.5%
	Standard deviation	23.08%	12.39%
	p-value	0.03*	
Rhythm recognition (Sub-test 3)	Minimum	20%	20%
	Maximum	100%	100%
	Mean	75.3%	75.8%
	Standard deviation	15.69%	15.17%
	p-value	0.44	
Rhythm perception (Sub-test 4)	Minimum	20%	10%
	Maximum	100%	100%
	Mean	63.75%	65%
	Standard deviation	24.76%	23.21%
	p-value	0.42	
Rhythm (Section A)	Minimum	42.5%	42.5%
	Maximum	97.5%	97.5%
	Mean	75.22%	77.63%
	Standard deviation	13.45%	11.56%
	p-value	0.06	

***Statistically significant benefit**

From the results displayed in Table 5-6 it is noticed that there is no significant benefit with the activation of NFC for rhythm identification, rhythm recognition and rhythm perception. This is also confirmed by the fact that the scores obtained with NFC active were similar to the average scores obtained by hearing aid users in the pilot study (rhythm identification: 84.5%; rhythm recognition: 78.5% and rhythm perception: 62%). A statistically significant benefit (p=0.03) with the activation of NFC was however obtained for the rhythm discrimination task. With the results of the different rhythm sub-tests calculated collectively, it seems that NFC does not significantly benefit the perception of rhythm and therefore the null hypothesis can be accepted. Furthermore, one can conclude that, on average, hearing aid users obtained lower scores than the normal hearing listeners that participated in the pilot study. Normal hearing participants obtained an average score of 95.2% for rhythm identification, 93.6% for rhythm discrimination, 89.1% for rhythm recognition and 89.7% for rhythm perception.

5.2.4 The influence of non-linear frequency compression on the perception of timbre (Sub-aim 3)

The next aim of the study was to determine the influence of non-linear frequency compression on the perception of timbre. Results for this section included responses to items from Section B of the MPT and specifically Sub-test 5 (Timbre identification – single and multiple instruments) and Sub-test 6 (Number of instruments).

Different music instruments were included in the MPT for assessment in the timbre section. These instruments included the cello, clarinet, piano, piccolo flute, saxophone, trombone, trumpet and violin. Participants were asked to first indicate their familiarity with each of these musical instruments before completing the timbre section of the test as they were evaluated on the instruments with which they were familiar only. The familiarity ratings for the different music instruments are displayed in Figure 5-10.

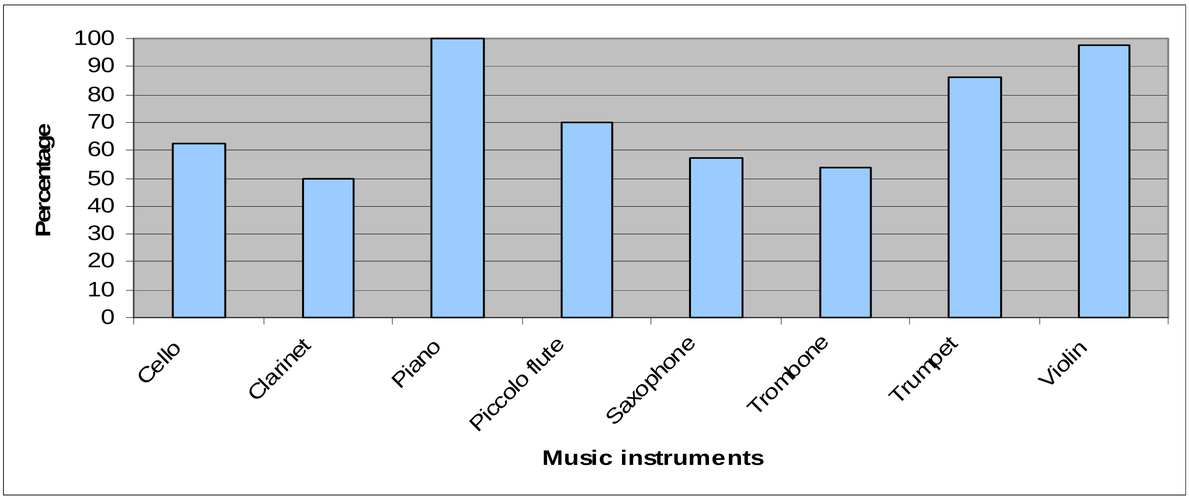

Figure 5-10 Participants familiarity with the musical instruments included in Sub-test 5

As can be seen in Figure 5-10, the piano was the most commonly known musical instrument and all the participants were familiar with its sound. This was also the instrument played by most participants (37.5% or n=15) as indicated in the first questionnaire. The second most common musical instrument was the violin, which was known by 97.5% (n=39) of the participants, followed by the trumpet which was familiar to 85% (n=34) of the participants and the piccolo flute which had a familiarity rating of 70% (n=28). Sixty-two percent (n=25) of the participants were familiar with the sound of a cello, followed by 57.5% (n=23) who felt that they could positively identify the saxophone. The instruments with which participants were least familiar included the trombone (55% or n=22) and the clarinet (50% or n=20).

After participants indicated their familiarity with the different musical instruments, they were asked to complete the timbre section of the MPT. For the first sub-test in this section participants were presented with melodic sequences played by the music instruments mentioned above. Participants were required to indicate which **musical instrument** produced each melodic sequence as presented in Figure 5-11.

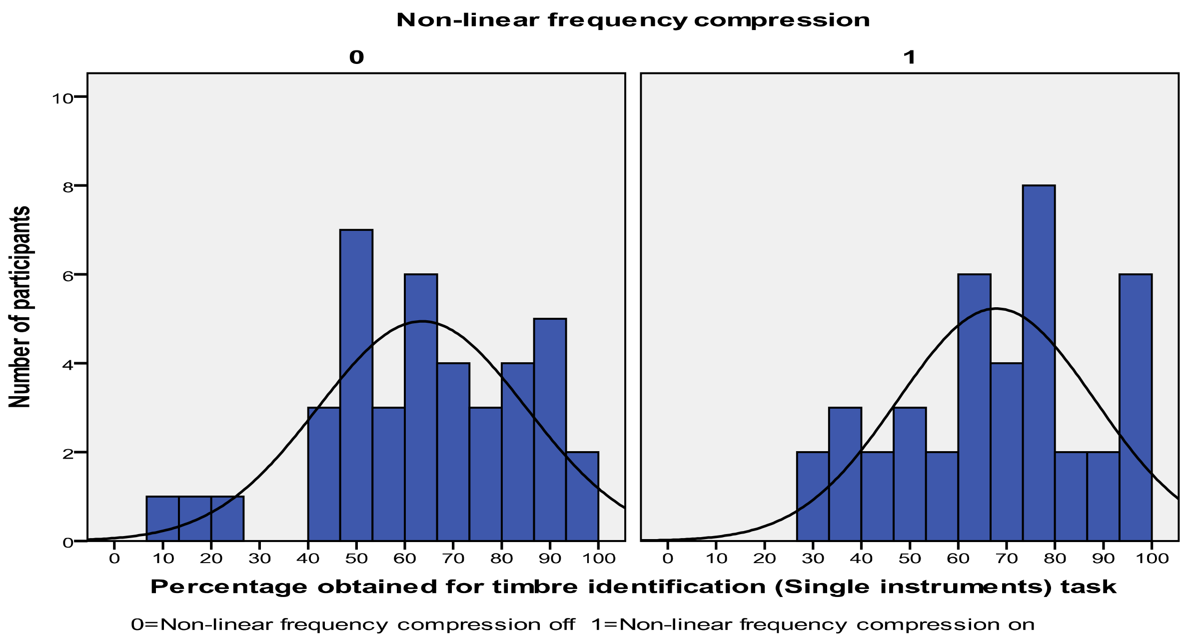

Figure 5-11: Participants' scores for timbre identification (Sub-test 5 – single instrument) with non-linear frequency compression off versus non-linear frequency compression on

Figure 5-11 shows that 35% of the participants (n=14) obtained a lower score with the activation of NFC while the activation of this algorithm resulted in a score increase of 52.5% of the participants (n=21). Large differences were seen in participants' scores with both NFC settings. For participants whose scores decreased with the activation of NFC, the decrease ranged from 2.5% to 50%, while those who performed better showed a score increase of between 2.1% and 55.2%.

The next task extended the investigation of timbre perception beyond single instrument identification. The data was obtained from Sub-test 5 (**Timbre identification – multiple instruments**) of the MPT. Different combinations of the same instruments used in the previous test played the same melodic piece in unison and participants were asked to identify which of the instruments were playing together in each melodic sequence. Results for this task are displayed in Figure 5-12.

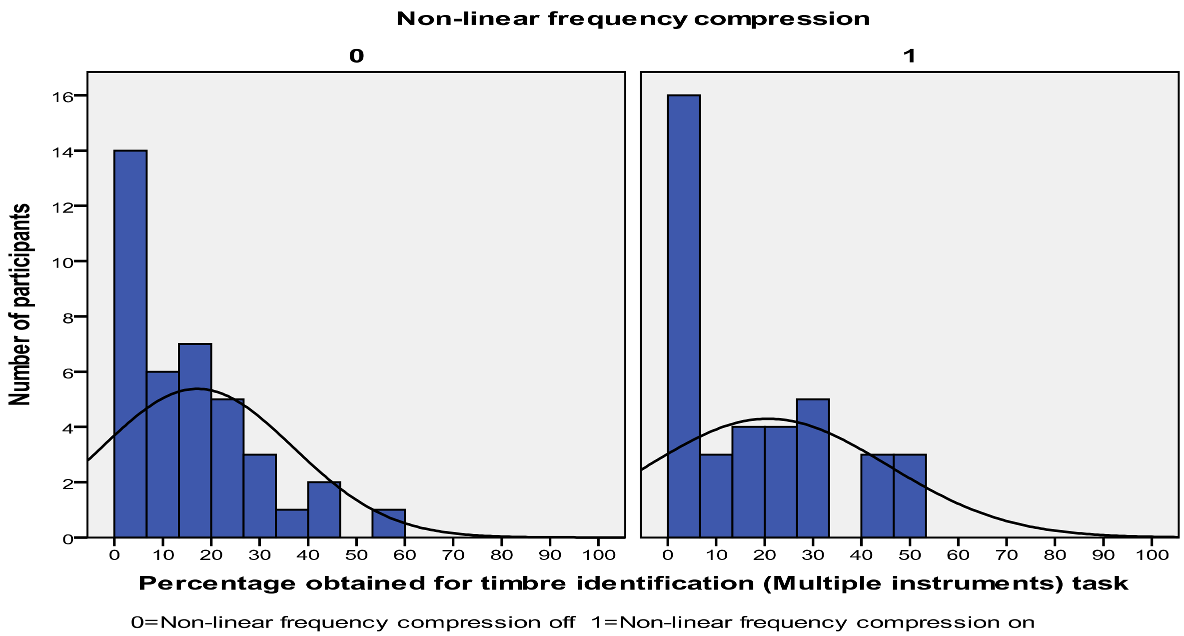

Figure 5-12: Participants' scores for timbre identification (Sub-test 5 – multiple instruments) with non-linear frequency compression off versus non-linear frequency compression on

For this task 30% of the participants (n=12) obtained the same score on both NFC settings. It should however be noted that in most cases this score was 0%. A total of 27.5% of participants (n=11) showed a decreased score (ranging between 2% and 37.5%) with the activation of NFC, while 42.5% of the participants (n=17) performed better (improvement of 6.3% to 100%) with this algorithm active.

The final task in the timbre section was similar to the identification of the multiple instruments task described above. Sub-test 6 of the MPT determined **how many different musical instruments** participants could distinguish in a short piece of music. Participants were presented with five different instruments (cello, piccolo flute, snare drum, trumpet and xylophone) selected to have timbres as different as possible. In this case, participants did not have to name the instruments they heard playing, but only identify the number of different instruments they heard in each melodic sequence. Results for this task are presented in Figure 5-13.

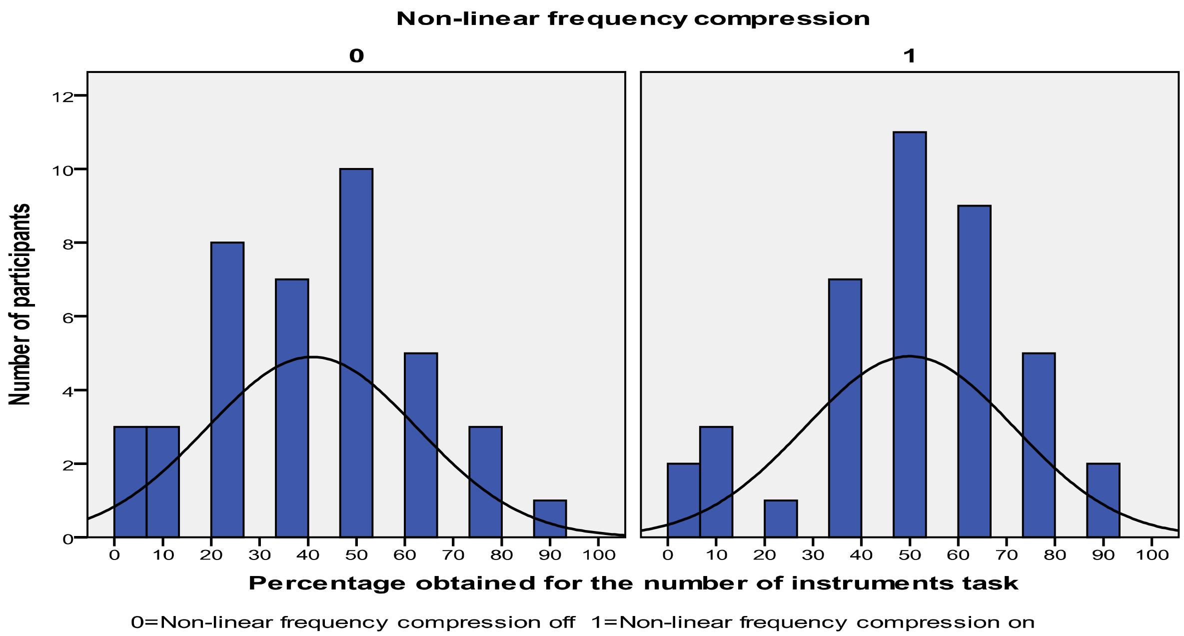

Figure 5-13: Participants' scores for the number of instruments task (Sub-test 6) with non-linear frequency compression off versus non-linear frequency compression on

Results displayed in Figure 5-13 indicate that for 22.5% of the participants (n=9) their scores decreased (ranging between 12% and 50%) with the activation of NFC while 50% of the participants (n=20) showed an increase (ranging between 12% and 50%) in their score. A total of

27.5% of the participants (n=11) experienced no difference in performance with the different NFC settings.

The scores for the three different timbre sub-tests were combined to determine whether there was an overall difference in participants' performance on **timbre** related tasks with NFC active versus NFC inactive. These results are displayed in Figure 5-14.

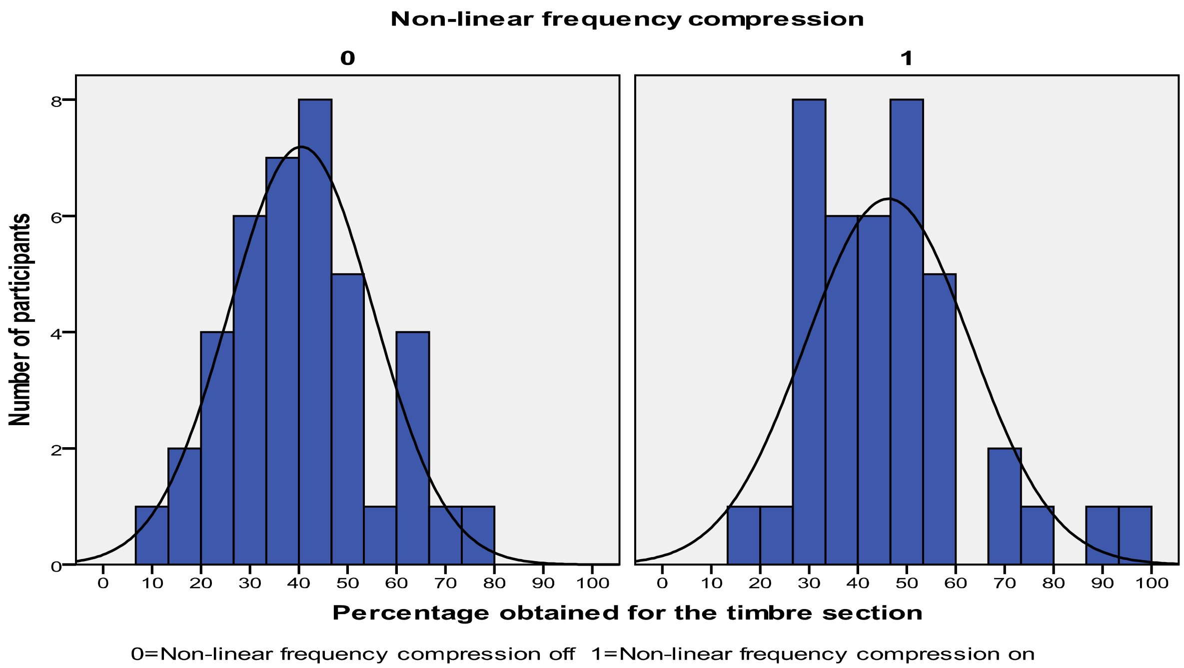

Figure 5-14: Participants' scores for the timbre section (Section 2) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

In total, 35% of the participants' (n=14) scores decreased with the activation of NFC while 65% of the participants' (n=26) scores increased when this algorithm was active. Differences in scores were highly variable and no pattern could be established.

Inferential statistics were again applied by conducting the paired t-test to determine whether participants benefited significantly in the perception of timbre by the activation on NFC. A summary of the data obtained is presented in Table 5-7.

Table 5-7: Descriptive inferential statistical values for the perception of timbre with non-linear frequency compression off versus non-linear frequency compression on

DESCRIPTIVE		NON-LINEAR FREQUENCY COMPRESSION OFF	NON-LINEAR FREQUENCY COMPRESSION ON
Timbre identification (Sub-test 5 – Single instruments)	Minimum	7.1%	31.3%
	Maximum	100%	100%
	Mean	63.56%	67.89%
	Standard deviation	21.52%	20.34%
	p-value	0.19	
Timbre identification (Sub-test 5 – Multiple instruments)	Minimum	0%	0%
	Maximum	100%	100%
	Mean	17.15%	20.75%
	Standard deviation	19.78%	24.77%
	p-value	0.25	
Number of instruments (Sub-test 6)	Minimum	0%	0%
	Maximum	88%	88%
	Mean	40.83%	49.95%
	Standard deviation	21.73%	21.65%
	p-value	0.049*	
Timbre (Section B)	Minimum	12.3%	16.2%
	Maximum	73.8%	96%
	Mean	40.52%	46.2%
	Standard deviation	14.77%	16.90%
	p-value	0.01*	

***Statistically significant benefit**

For the timbre identification tasks (single and multiple instruments) participants did not obtain a statistically significant benefit with NFC. It is however evident that participants' increase in performance on the number of instruments task as well as their overall performance on the timbre section of the MPT were statistically significant. This implies that, for the perception of timbre, the null hypothesis can be rejected as the results above confirm that the activation of NFC resulted in improved timbre perception. Again hearing aid users scored significantly lower than normal hearing listeners on the different timbre sub-tests; normal hearing listeners obtained a mean score of 86.6% for the single instrument identification task, 81% for the multiple instrument identification task and 81% for the number of instruments task.

5.2.5 The influence of non-linear frequency compression on the perception of pitch (Sub-aim 4)

The next aim of the study was to determine the influence of non-linear frequency compression on the perception of pitch. The reflected results include responses to items from Section C of the MPT and specifically Sub-test 7 (Pitch identification) and Sub-test 8 (Pitch discrimination).

In experiments that require participants to detect whether two sounds differ, or which one of three or more sounds differ from the others; the ability under investigation is *discrimination* (McDermott, 2004:66). In practice, participants may use any perceptible differences between the sounds to perform the task. However, if subjects are asked to listen to two sounds presented in sequence, and to judge which one has the higher pitch, the procedure is often called *pitch ranking*. The experimental context, or the parameters of the stimuli, assumes that the varying sound quality used by the participants in such tasks is pitch. It is of course possible that some other quality of the signals that changes, such as timbre or even loudness, may enable at least some subjects to successfully rank the stimuli (McDermott, 2004:66).

For the assessment of pitch in the present study, a pitch discrimination task and a pitch-ranking task, referred to as pitch identification, were included in the MPT. The **pitch identification** task involved discrimination of complex pitch change where participants were presented with pairs of two tones each. On each presentation, a tone at the reference frequency and a higher/lower pitched tone were played in random order. Participants had to identify whether the second tone was higher or lower in pitch than the base tone. Results for this test are presented in Figure 5-15.

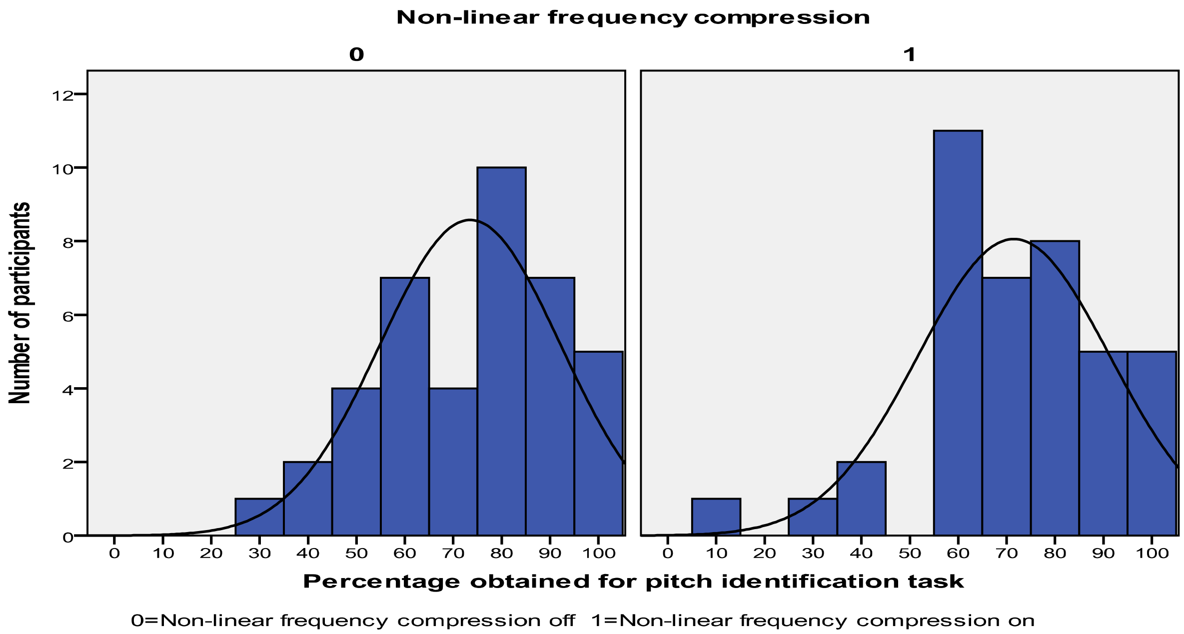

Figure 5-15: Participants' score for the pitch identification task (Sub-test 7) with non-linear frequency compression off versus non-linear frequency compression on

For almost a third of the participants (35% or n=14) the different NFC settings did not have any influence on performance as they scored exactly the same on the pitch identification task with NFC active or inactive. The majority of the participants (40% or n=16) showed a decrease in scores when the NFC algorithm was activated, while only 25% of the participants' (n=10) scores increased with the activation of this technology.

A second pitch task, called **pitch discrimination**, was presented. This task determined a participant's ability to distinguish between different pitches. Participants were presented with pairs of melodic sequences which had equivalent rhythmic patterns but varied in frequency on one or more notes. They were asked to indicate whether the melodic sequences in each pair were the same or different. These results are summarized in Figure 5-16.

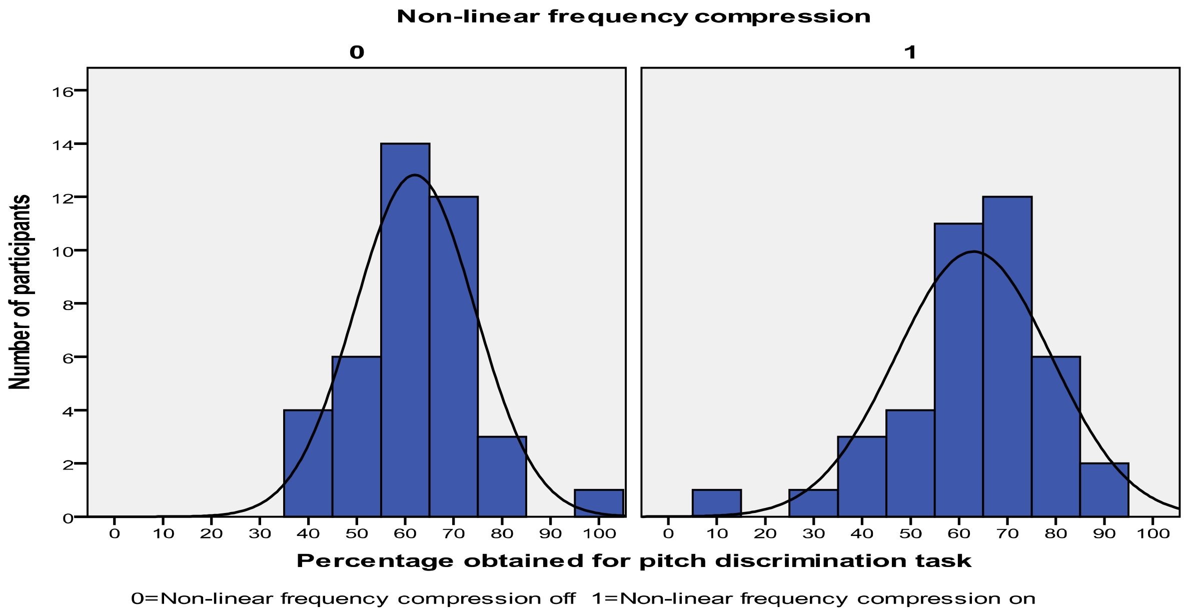

Figure 5-16: Participants' score for the pitch discrimination task (Sub-test 8) with non-linear frequency compression off versus non-linear frequency compression on

For the task described above, 45% of the participants (n=18) showed a positive outcome with the activation of NFC, while 32.5% of the participants (n=13) found that the activation of this algorithm influenced their performance negatively. For 22.5% of the participants (n=9) no difference in performance was seen.

To determine the average score for the **pitch section** of the MPT, participants' scores for the pitch identification (Sub-test 7) and pitch discrimination (Sub-test 8) tasks were calculated together to determine an average score. A summary of the results is displayed in Figure 5-17.

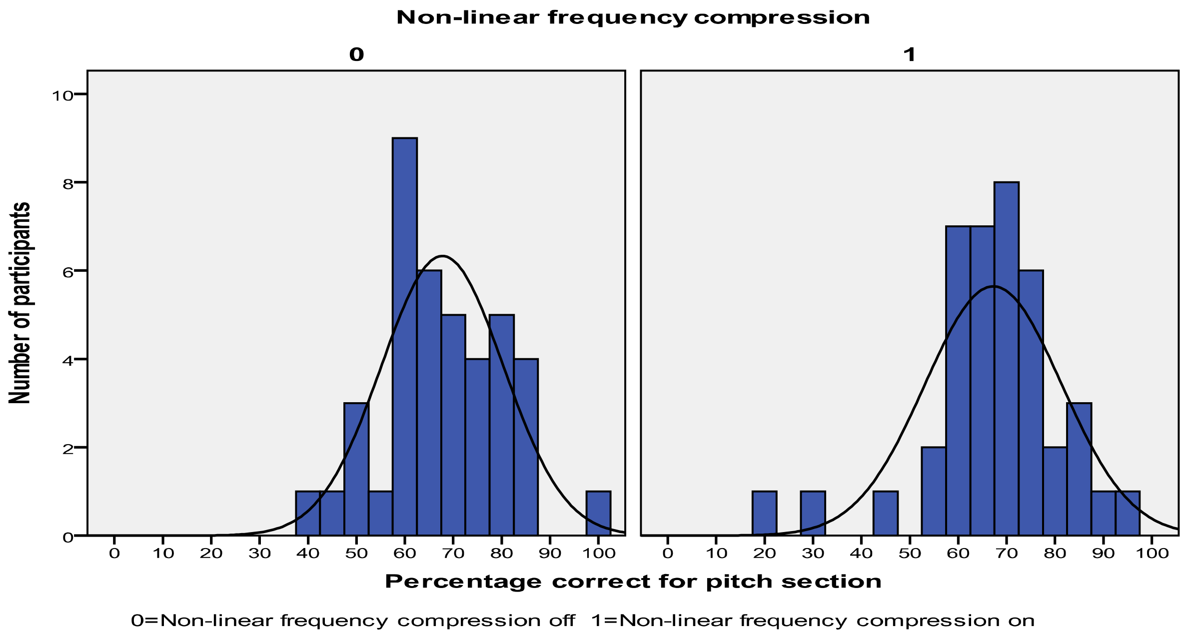

Figure 5-17: Participants' scores for the pitch section (Section 3) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

As shown in the Figure 5-17, the majority of participants (45% or n=18) obtained a lower score for the pitch section of the MPT with the activation of NFC. For 35% of the participants (n=14) the activation of NFC resulted in increased performance while only 20% of the participants (n=8) were neither favoured nor hampered by the activation of this algorithm. For participants whose scores decreased, only 22% (2 of 18) showed a decrease of more than 10% (equivalent to one answer in the MPT) while 36% (5 of 14) of the participants showed a score increase of more than 10%.

Table 5-8 presents the summarized descriptive statistical values for the different pitch tasks with NFC off versus NFC on as displayed in Figures 5-15 to 5-17. The paired t-test was again used in the calculation of these values.

Table 5-8: Descriptive inferential statistical values for the perception of pitch with non-linear frequency compression off versus non-linear frequency compression on

DESCRIPTIVE		NON-LINEAR FREQUENCY COMPRESSION OFF	NON-LINEAR FREQUENCY COMPRESSION ON
Pitch identification (Sub-test 7)	Minimum	30%	10%
	Maximum	100%	100%
	Mean	73.5%	71.5%
	Standard deviation	18.61%	19.81%
	p-value	0.34	
Pitch discrimination (Sub-test 8)	Minimum	40%	10%
	Maximum	100%	90%
	Mean	62.0%	63.0%
	Standard deviation	12.45%	16.05%
	p-value	0.39	
Pitch (Section 3)	Minimum	40%	20%
	Maximum	100%	95%
	Mean	67.75%	67.25%
	Standard deviation	12.61%	14.14%
	p-value	0.40	

The data presented in Table 5-8 confirms that there was no statistically significant benefit with the activation of NFC technology for the pitch identification and pitch discrimination tasks. This is also confirmed by similar scores obtained by hearing aid users in the pilot study who had a mean score of 74% for the pitch identification and 67.5% for the pitch discrimination tasks. These performances resulted in the fact that participants did not experience a significant benefit for the pitch section of the MPT with activation of NFC and therefore the null hypothesis can be accepted since one may conclude that NFC does not contribute to a significant improvement in the perception of pitch for hearing aid users with a moderate to severe hearing loss. Again, hearing aid users obtained lower scores than normal hearing participants who presented a mean score of 92.4% for the pitch identification and 80.8% for the pitch discrimination tasks.

5.2.6 <u>The influence of non-linear frequency compression on the perception of melody (Sub-aim 5)</u>

The last section of the MPT aimed at determining the influence of non-linear frequency compression on the perception of melody. This was done with three melody related tasks which included musicality perception (Sub-test 9), melody identification (Sub-test 10) and music-in-noise song identification (Sub-test 11).

For the **musicality perception** task, participants were presented with pairs of short melodic sequences. Some of the melodies in the pairs were random notes, making no musical sense, while others were musical pieces with a clear melodic structure. Participants had to indicate which of the melodic sequences were musical. The results of this task are shown in Figure 5-18.

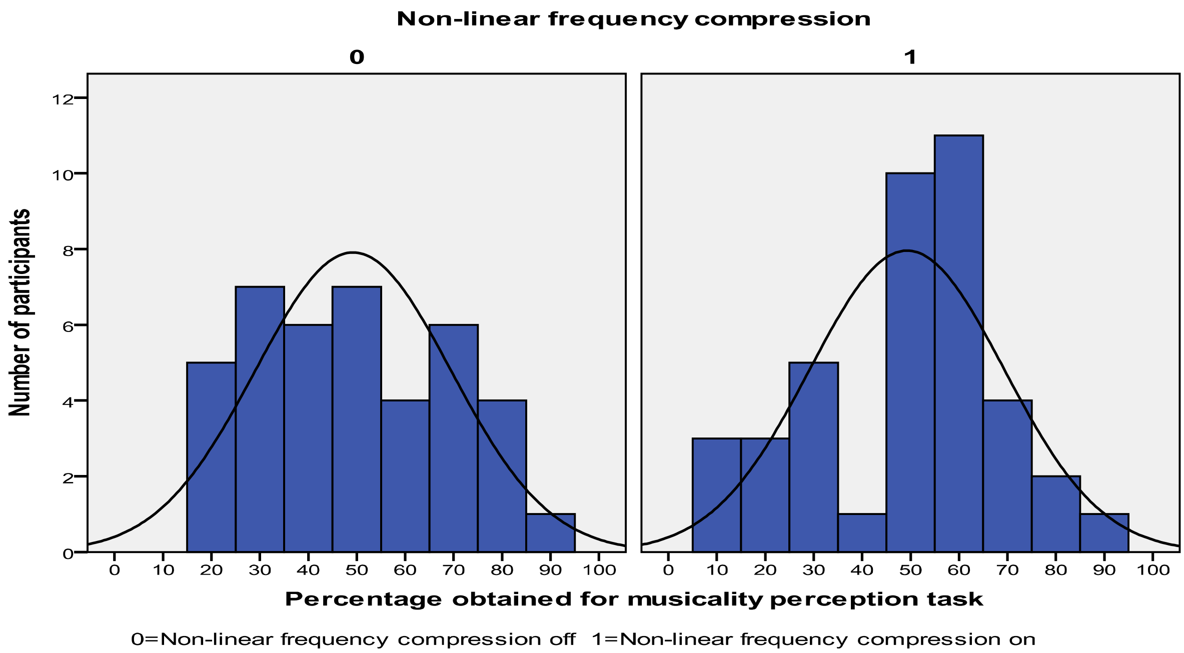

Figure 5-18: Participants' scores for the musicality perception task (Sub-test 9) with non-linear frequency compression off versus non-linear frequency compression on

According to Figure 5-18 42.5% of the participants (n=17) showed a score increase with the activation of NFC, while 32.5% of the participants' (n=13) scores decreased when NFC was activated. For 25% of the participants (n=10) no score differences was obtained with the different NFC settings.

The next task assessed **familiar melody identification**. An important aspect to consider was whether melodies were sufficiently familiar to listeners to enable them to name the melody on hearing it. This ability depends on a range of highly variable factors, such as one's musical training and listening experience, the social culture within which that experience was gained, and the person's memory of both the tunes and their titles (McDermott, 2004:59). Recognition is also likely to be affected by the situational context in which the music is heard. For example, in the western musical culture, 'Happy birthday to you' is rated amongst the most familiar melodies for the general population, and it is immediately recognizable by nearly everyone in the appropriate circumstances regardless of the intonation of the notes, the correctness of the rhythm, or the acoustical quality of the listening situation. Thus, the ability to accurately perceive fundamental features of musical sounds such as pitch and temporal patterns, is not always a pre-requisite for melody recognition, because both rhythm and pitch information contribute to a person's ability to perceive melodies accurately (Looi *et al.*, 2008b:422; Kong *et al.*, 2004:183). Furthermore, it seems that recognition of just a few words in a well-known song may be sufficient for many listeners to name it correctly (McDermott, 2004:59).

To ensure that it was identification abilities being assessed during the melody identification task and not musical knowledge, each participant's familiarity with the melodies was verified before testing (Looi *et al.*, 2008b:426). Participants were given an alphabetical list of melodies and were instructed to mark all the melodies that were familiar to them. The final score was noted as a percentage of correct responses on the melodies with which the listener was familiar. Those items missed in the test were cross-checked with the list completed beforehand. If an item was missed, and it was not listed as familiar, that item was eliminated from the analysis. The results are displayed in Figure 5-19.

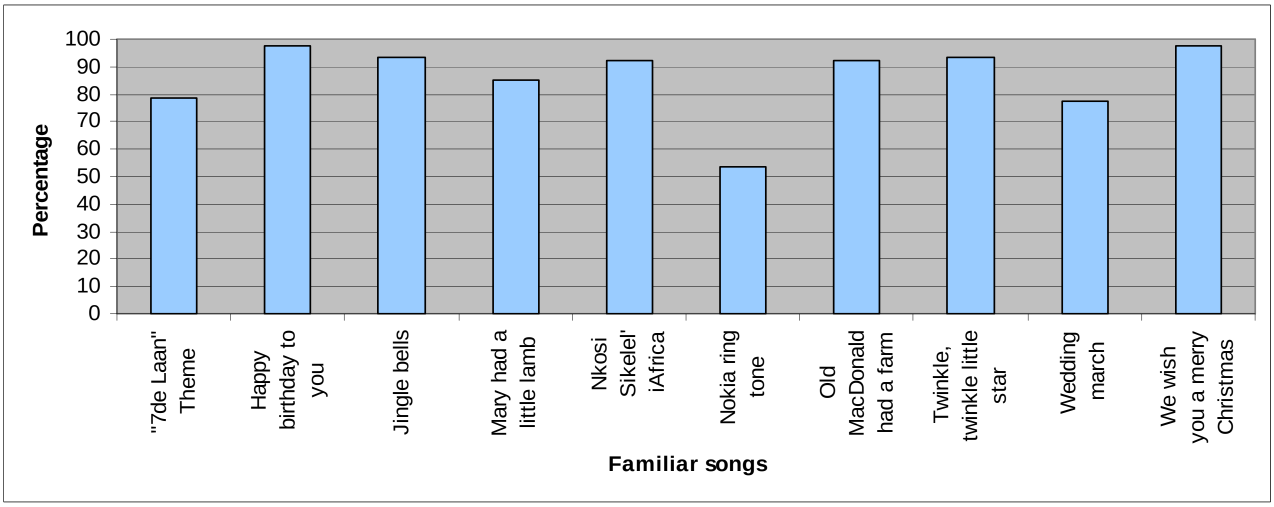

Figure 5-19: Participants' familiarity with the melodies included in Sub-test 10 of the Music Perception Test

Figure 5-19 displays that all the songs included in the melody identification task was known to more than 75% of the participants except for one, the *Nokia ring tone*, which was familiar to only 54% of the participants. The most familiar songs were *Happy birthday to you* (97.5%) and *We wish you a merry Christmas* (97.5%), followed by *Jingle bells* (93.8%) and *Twinkle, twinkle little star* (93.8%). Other songs viewed as familiar included *Nkosi Sikelel' iAfrica* (92.5%), *Old MacDonald had a farm* (92.5%), *Mary had a little lamb* (85%), '*7de Laan' theme song* (78.8%) and the *Wedding march* (77.5%).

The songs *Happy birthday to you, Jingle bells, Mary had a little lamb, Old MacDonald had a farm, Twinkle, twinkle little star* and *We wish you a merry Christmas* were already proved as familiar in international studies (Looi *et al.*, 2008b:425; Nimmons *et al.*, 2008:152; Galvin *et al.*, 2007:306; Kong *et al.*, 2005:1356). The other four songs were included based on their high exposure in the South African context which led to the assumption that they would be familiar to the South African population. Three of these songs ('*7de Laan' theme song, Nkosi Sikelel iAfrica, Wedding march*) were known by more than 75% of the participants and one may therefore conclude that these songs have a high rate of familiarity in the South African context. Although the one less known melody, the *Nokia ring tone*, is common in South Africa, it is recommended to rather replace this melody by a more familiar one in future studies.

After participants indicated their familiarity with the songs they were asked to complete the **melody identification** task. In this sub-test participants were asked to identify the melodies mentioned above with and without rhythm cues. These results are presented in Figure 5-20.

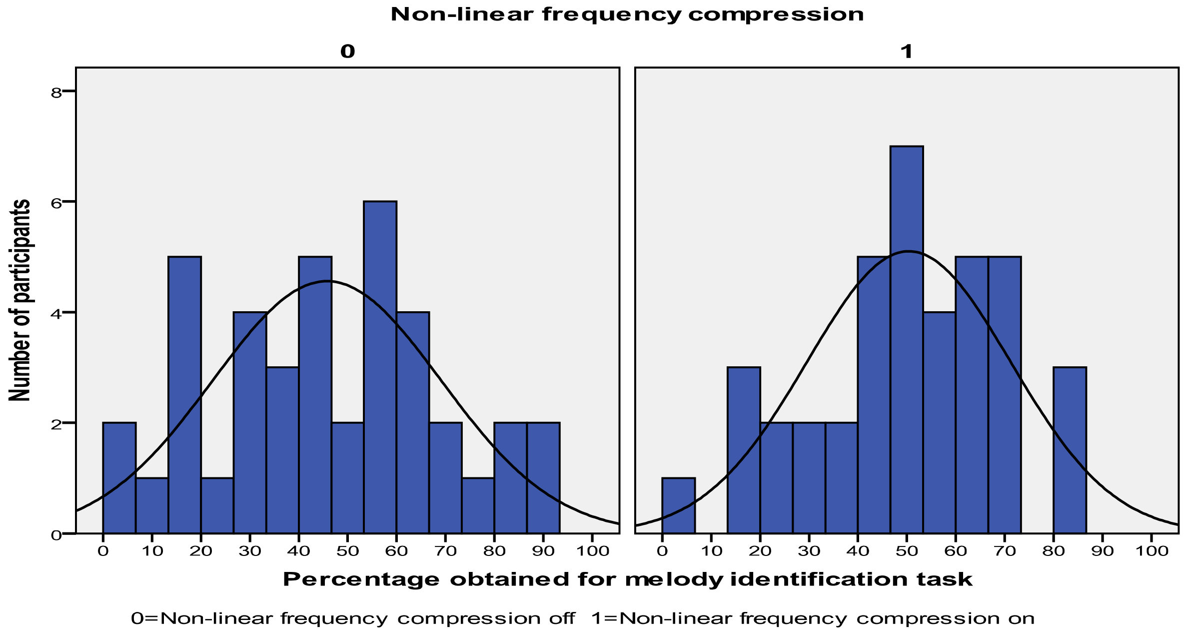

Figure 5-20: Participants' scores for the melody identification task (Sub-test 10) with non-linear frequency compression off versus non-linear frequency compression on

For this task, only 10% of the participants (n=4) obtained the same score on both NFC settings. A total of 55% of the participants (n=22) showed increased scores with the activation of NFC, while 35% of the participants (n=14) obtained lower scores when this algorithm was active.

The last sub-test in the melody section of the MPT involved the identification of familiar movie **soundtracks in the presence of background noise**. The same procedure was followed as for the melody identification task in the sense that, prior to conducting the actual test, participants first had to indicate which of the soundtracks they were familiar with. They were again only assessed on the items with which they were familiar. The soundtracks included in this sub-test and the percentage of participants who were familiar with them, are displayed in Figure 5-21.

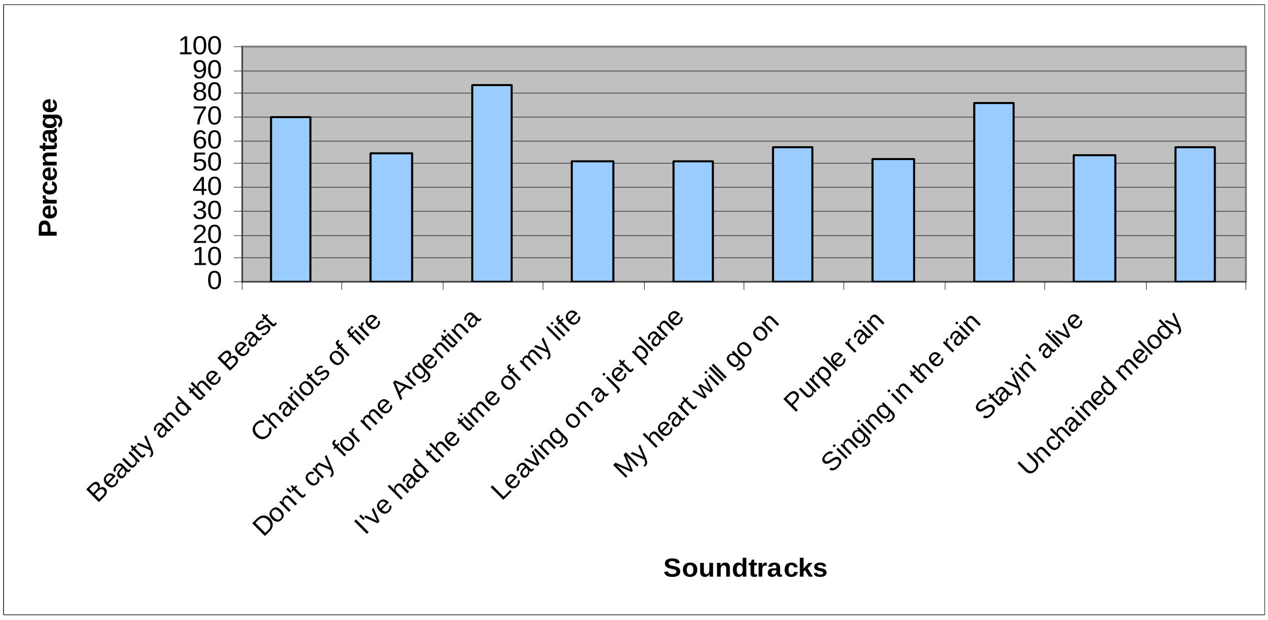

Figure 5-21: Participants' familiarity with the soundtracks included in Sub-test 11 of the Music Perception Test

The soundtracks included in Sub-test 11 were less familiar to participants than the melodies used in Sub-test 10. This however was not surprising, since the melodies selected in Sub-test 10 were specifically selected because of their familiarity. Three of the soundtracks used in Sub-test 11 were known by more than 70% of the participants and included: *Don't cry for my Argentina* (83.8%), *Singing in the rain* (76.3%) and *Beauty and the beast* (70%). More than half of the participants were familiar with the rest of the soundtracks used in this sub-test. The soundtrack familiarity were ranked as *My heart will go on* (57.5%), *Unchained melody* (57%), *Chariots of fire* (55%), *Stayin' alive* (53.8%), *Purple rain* (52.5%), *Leaving on a jet plane* (51.3%) and *I've had the time of my life* (51.3%). Although these soundtracks did not have such a high rate of familiarity, it is important to remember that participants were only assessed on the soundtracks that were familiar to them and therefore were not penalized if they did not know a specific soundtrack.

After participants indicated with which of the soundtracks they were familiar, they continued with the test. Results of this sub-test are displayed in Figure 5-22.

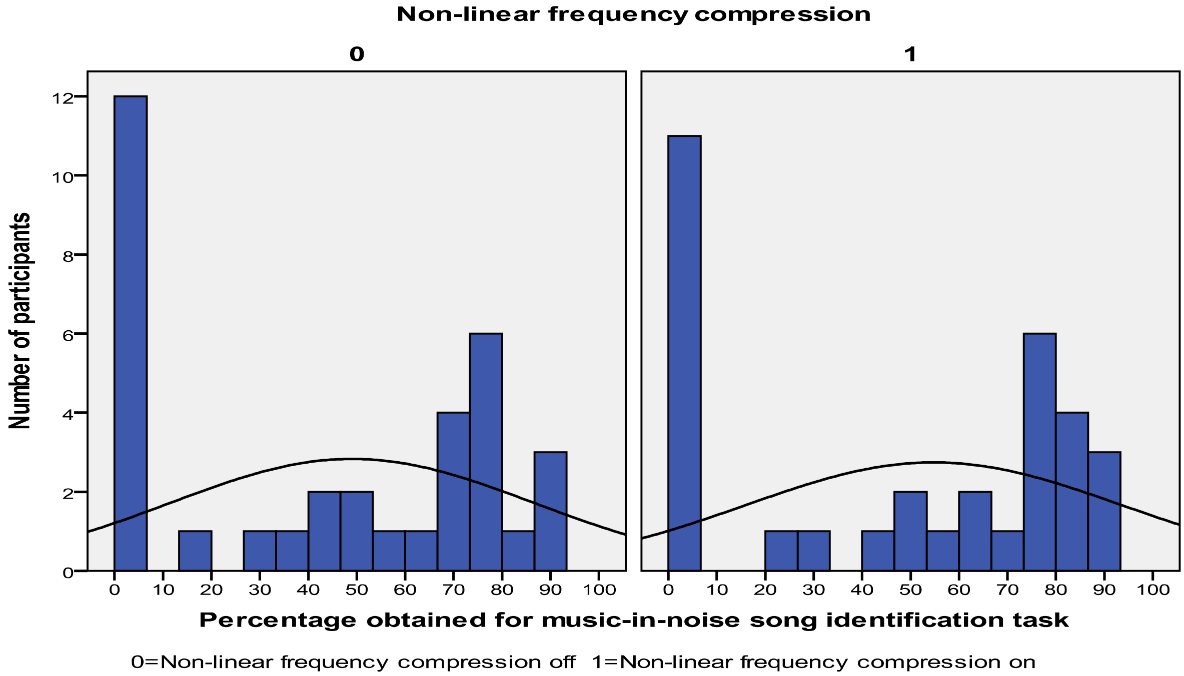

Figure 5-22: Participants' scores for the music-in-noise song identification task (Sub-test 11) with non-linear frequency compression off versus non-linear frequency compression on

For this task, 35% of the participants (n=14) obtained the same score on both NFC settings. It should however be mentioned that 64% (n=9) of them had a score of 0% in both cases; they indicated that this task was difficult due to the high levels of background noise. For another 45% of the participants (n=18) the activation of NFC resulted in increased performance while only 20% of the participants' (n=8) performances decreased when this algorithm was activated.

To establish what the effect of NFC on **melody perception** was, the scores for the musicality perception, melody identification and music-in-noise song identification tasks were calculated together. The resulting data is summarized in Figure 5-23.

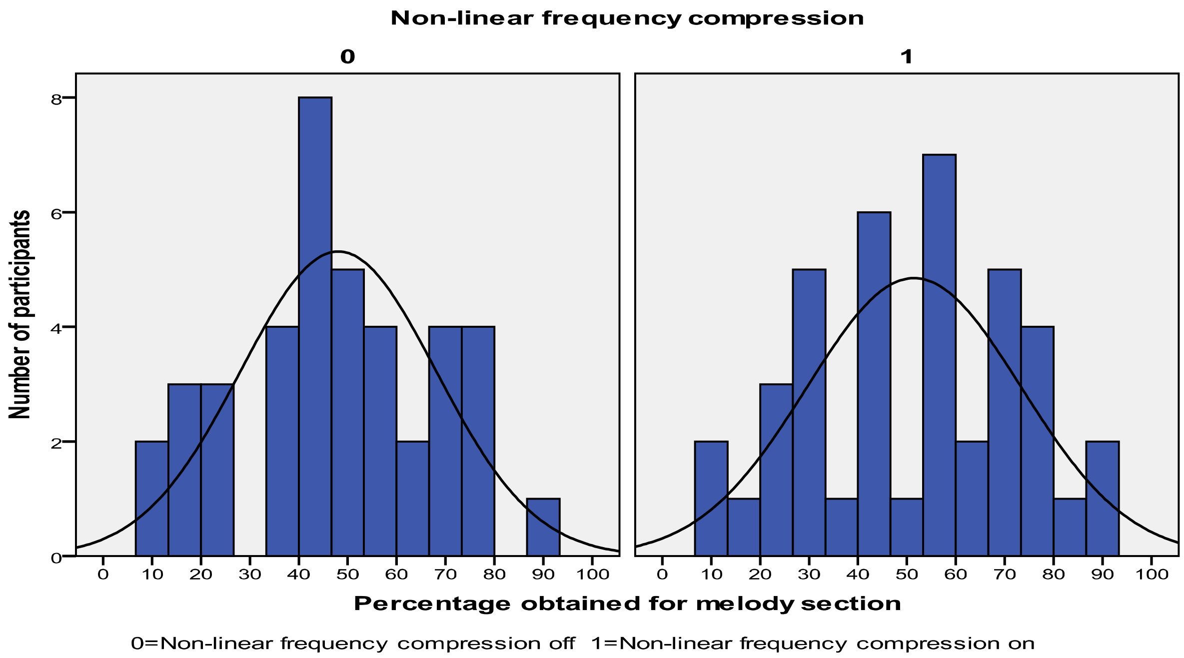

Figure 5-23: Participants' scores for the melody section (Section 4) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

In total, 62.5% of the participants (n=25) showed an increase in their overall score with the activation of NFC while only 37.5% of the participants' (n=15) scores decreased with the use of NFC. The results were once again characterized by high rates of variability.

Table 5-9 presents the summarized descriptive inferential statistical values for the perception of melody with NFC off versus NFC on.

Table 5-9: Descriptive inferential statistical values for the perception of melody with non-linear frequency compression off versus non-linear frequency compression on

DESCRIPTIVE		NON-LINEAR FREQUENCY COMPRESSION OFF	NON-LINEAR FREQUENCY COMPRESSION ON
Musicality perception (Sub-test 9)	Minimum	20%	10%
	Maximum	90%	90%
	Mean	49.25%	49.25%
	Standard deviation	20.18%	20.05%
	p-value	0.5	
Melody identification (Sub-test 10)	Minimum	0%	0%
	Maximum	90%	100%
	Mean	45.76%	50.39%
	Standard deviation	23.34%	20.86%
	p-value	0.22	
Music-in-noise song identification (Sub-test 11)	Minimum	0%	0%
	Maximum	100%	100%
	Mean	49.04%	54.77%
	Standard deviation	37.59%	38.79%
	p-value	0.28	
Melody perception (Section 4)	Minimum	11.4%	8.1%
	Maximum	90%	93.3%
	Mean	48.09%	51.47%
	Standard deviation	20.02%	21.94%
	p-value	0.04*	

***Statistically significant benefit**

According to the paired t-test analysis, no statistical significant benefit existed for the performance on the musicality perception, melody identification and music-in-noise song identification tasks with NFC active compared to being inactive. For all three these tasks, the mean scores were worse than the mean scores obtained by hearing aid users in the pilot study who obtained 54.5% for the musicality perception task, 68% for the melody identification task and 63.2% for the music-in-noise song identification task. No specific explanation could be found for the large score differences between the participants in the main study and the hearing aid users in the pilot study; they complied to the same selection criteria, had roughly the same average age (participants 57.5 years and hearing aid users in pilot study 55.9 years) and negligible differences in the level of musical training. Again, hearing aid users performed much poorer than normal hearing listeners; the participants with normal hearing scored an average of 84% for the musicality perception task, 90.3% for the melody identification task and 93.4% for the music-in-noise song identification task in the pilot study.

It is, however, interesting to note that although none of the performances on the sub-tests in the melody section of the MPT resulted in a significant benefit by activating NFC it seems that, overall, participants experienced a significant improvement in the perception of melodies when NFC was activated. This results in the acceptance of the alternative hypothesis which states that NFC significantly improves the perception of melodies for hearing aid users with a moderate to severe hearing loss.

5.2.7 <u>The influence of non-linear frequency compression on participants' subjective impression of listening to music (Sub-aim 6)</u>

The next sub-aim of the study was to determine the influence of non-linear frequency compression on participants' subjective impression of listening to music. This information was obtained from the second questionnaire.

As mentioned previously, the music genres that people listen to may influence their perception of the quality of music. Figure 5-24 displays participants' preferences regarding musical genres.

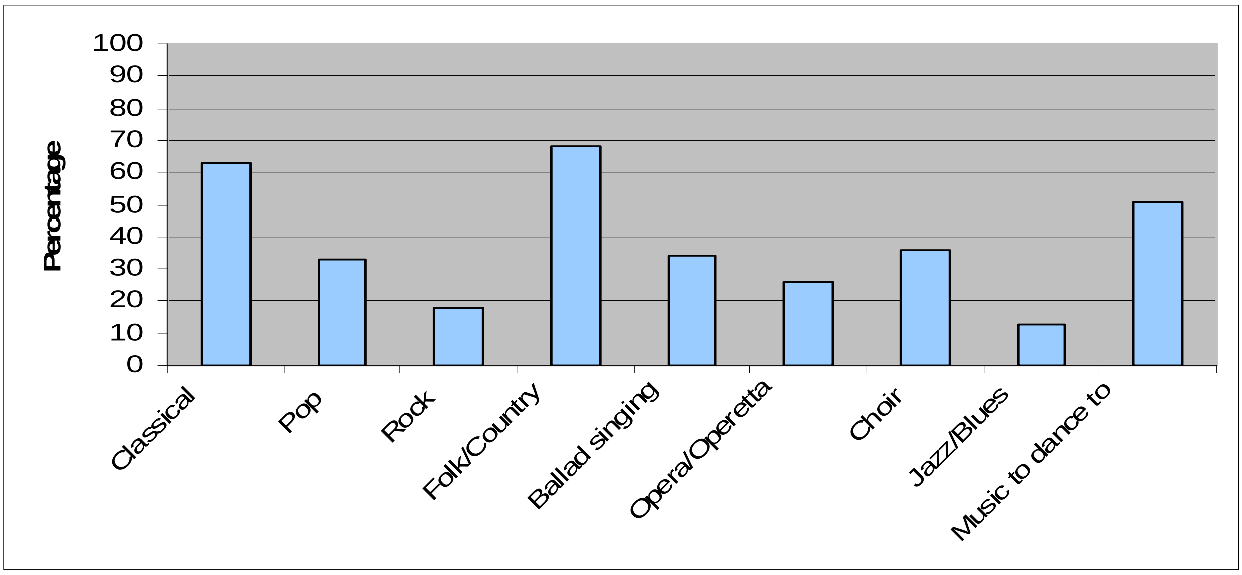

Figure 5-24: Participants' preferences regarding musical genres

According to the responses to the second questionnaire, most of the participants prefer to listen to folk/country music (67.5%), followed by classical music (62.5%) and music to dance to (51.3%). Folk/country music often focuses upon stories of everyday life with lyrics often being a key aspect of this music genre while classical music can be categorized into broad styles with distinct structural features (e.g. baroque music, classical music, romantic music) and tend to have more complex, sophisticated melodic, harmonic and rhythmic structures than those found in other genres (Gfeller *et al.*, 2005:241). Fewer participants enjoyed choir music (36.3%), ballad singing (33.8%), pop music (32.5%) and opera/operetta (26.3%). The music genres least preferred by participants were rock music (17.5%) and jazz/blues (12.5%).

Studies of music enjoyment by persons with a hearing loss are rather rare in the literature (Leek *et al.*, 2008:521) and it is not known how common it is for persons with a hearing loss to find music unpleasant or distorted, nor how debilitating and distressing this reaction might be to these persons. Participants in the present study were asked to give a subjective impression of how they experienced listening to music with and without NFC by completing a rating scale included in Questionnaire 2. Musical qualities assessed with this scale included loudness, fullness, crispness, naturalness, overall fidelity, pleasantness, tinniness and reverberance. Figures 5-25 to 5-32 display the average scores for participants on the assessment of these musical qualities. A higher score for the adjectives loud, full, crisp or clear, natural and pleasant indicates better sound quality, whereas a higher score for the adjectives constrained or narrow, more tinny and echoing generally indicate less desirable sound quality. In order to determine whether the application of NFC resulted in significant benefits for the qualities above, the Wilcoxon matched-pairs signed rank test was used. This test is appropriate for studies involving repeated measures in which the same subjects serve as their own control (Maxwell & Satake, 2006:340). It was therefore applicable to the results obtained from the second questionnaire because this questionnaire was non-parametric due to the ranking scale used. Furthermore, participants had to complete the questionnaire twice as they were asked to give their impression on the different musical qualities with and without NFC.

The first musical quality to be assessed was **loudness**. For the purpose of this study, musical loudness was defined as: ‘The music is sufficiently loud, as opposed to soft or faint’. Hearing aid users' perception of the loudness of music when listened to with and without NFC is displayed in Figure 5-25.

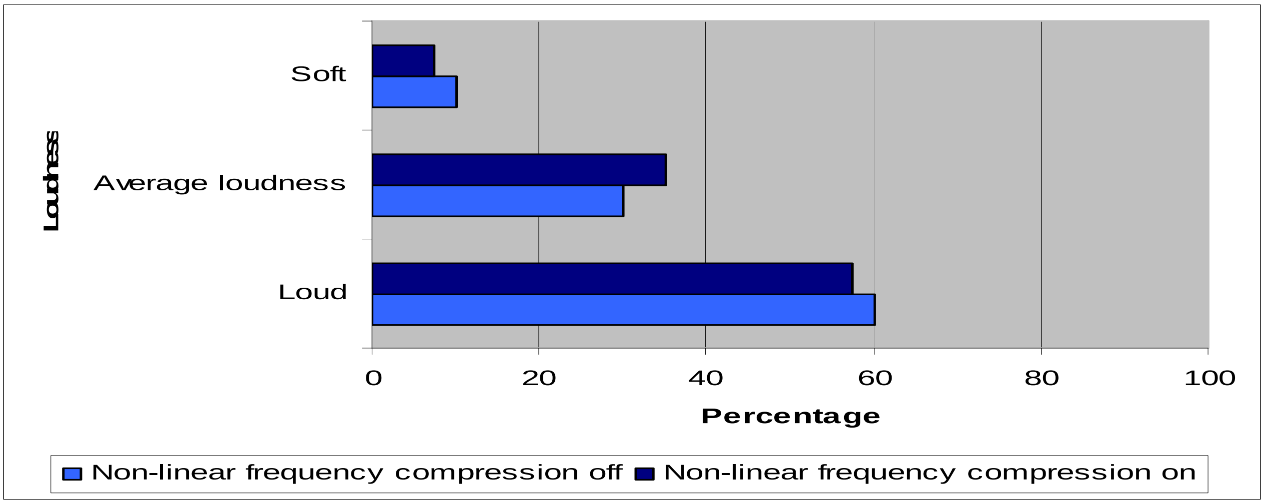

Figure 5-25: Participants' perception of musical loudness with non-linear frequency compression off versus non-linear frequency compression on

According to Figure 5-25 most participants felt that music was sufficiently loud with the hearing aids and there was only a slight difference in the loudness quality rating with NFC off versus NFC on. With the NFC algorithm active, 57.5% (n=23) of the participants were satisfied with the loudness, 35% (n=14) felt that the loudness of the music was only average and could still improve and 7.5% (n=3) complained that the music was too soft. When assessed with NFC off, 60% (n=24) felt that the music was sufficiently loud, with another 30% (n=12) of the participants who concluded that the music was audible but preferred it to be louder. Ten percent (n=3) indicated that the music was too soft. Results for the different NFC settings were very similar and therefore no significant benefit (p=0.43) was obtained with this algorithm active.

The next musical quality to be assessed was the **fullness** of music. Fullness was described to participants as: 'The music is full, as opposed to thin'. The results of this assessment are displayed in Figure 5-26.

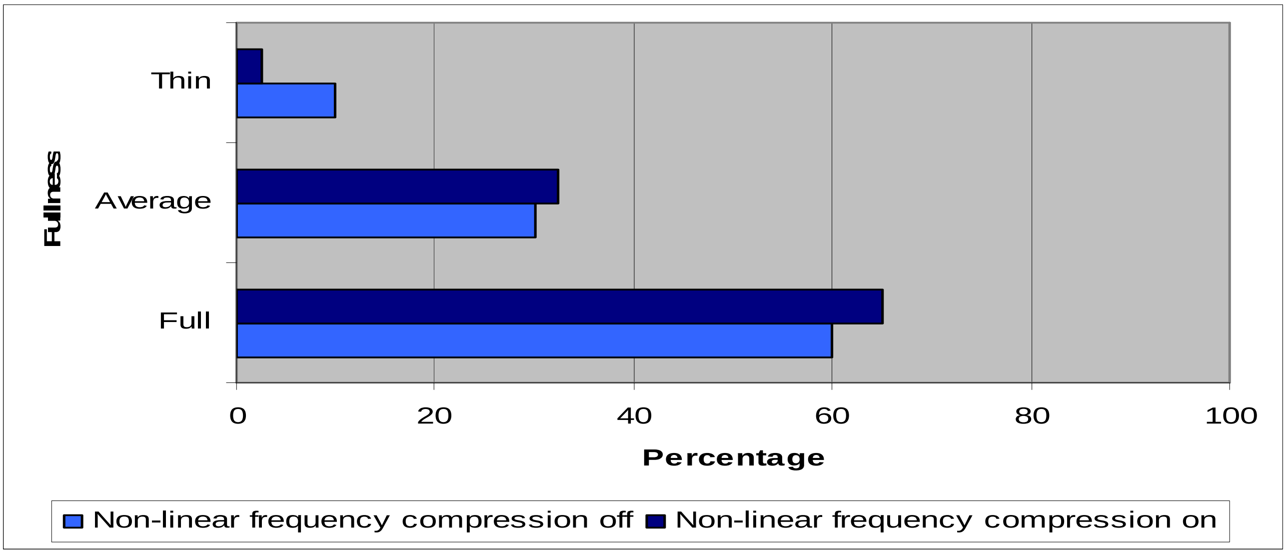

Figure 5-26: Participants' perception of the fullness of music with non-linear frequency compression off versus non-linear frequency compression on

From Figure 5-26 it is clear that when NFC was active, there was a slight improvement in participants' rating of the fullness of music compared to when NFC was inactive. This improvement was, however, not statistically significant (p=0.31). Sixty five percent (n=26) of the participants indicated that the music sounded full as opposed to thin with NFC active compared to 60% (n=24) when NFC was inactive. With NFC active, 32.5% (n=13) of the participants rated the fullness as average, with only one participant who felt that the music sounded thin. With NFC inactive, 30% (n=12) of the participants found the fullness of music to be average and another 10% (n=4) found the music to be thin rather than to be full.

In order to assist participants in understanding the musical quality of **crispness**, it was defined as: 'The music is clear and distinct, as opposed to blurred and diffuse'. Participants' assessment of the crispness of music with both non-linear frequency compression settings is displayed in Figure 5-27.

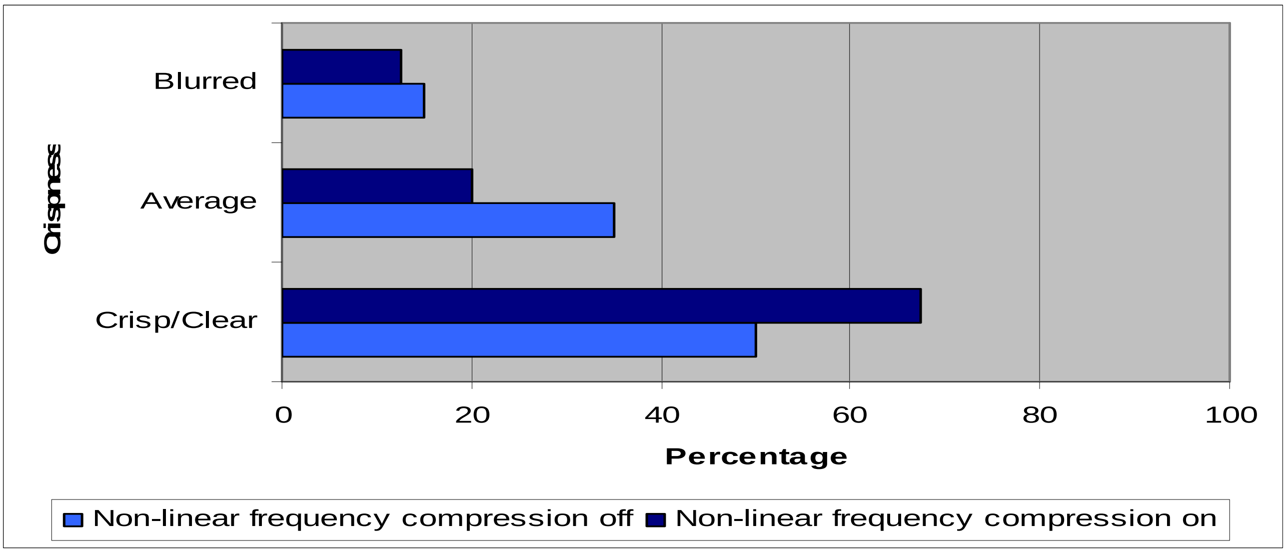

Figure 5-27: Participants' perception of the crispness of music with non-linear frequency compression off versus non-linear frequency compression on

When asked about the crispness, 67.5% (n=27) of the participants concluded that the music was clear and distinct with NFC on, compared to 50% (n=20) when NFC was off. An average rating was provided by 20% (n=8) of the participants with NFC on and by 35% (n=14) with NFC off. For 12.5% (n=5) of the participants the music sounded blurred and diffuse with NFC on. The same phenomenon was experienced by 15% (n=6) of the participants with NFC off. Again the improved quality experienced with NFC active was not significant (p=0.11)

Another musical quality that participants were asked to evaluate was the **naturalness** of music. For the purpose of this study, musical naturalness was defined as: 'The music seems to be as if there is no hearing aid and as I remember it'. This information is presented in Figure 5-28.

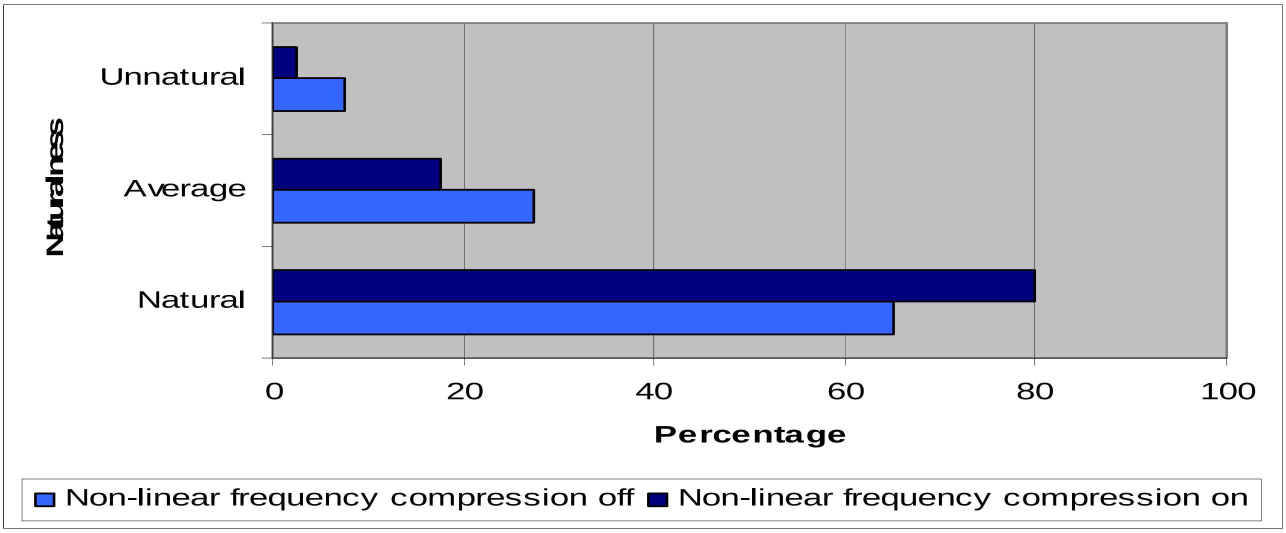

Figure 5-28: Participants' perception of the naturalness of music with non-linear frequency compression off versus non-linear frequency compression on

Figure 5-29 shows that 80% (n=32) of the participants experienced the quality of music as natural, 17.5% (n=7) as average and only one participant as unnatural when NFC was active. When NFC was inactive, 65% (n=26) of the participants were satisfied with the natural quality of music, 27.5% (n=11) found the naturalness to be average and 7.5% (n=3) of the participants described the music as sounding unnatural. It therefore seems that music sounds more natural with the activation of NFC but again the benefit was not found to be statistically significant (p=0.09).

Participants were then also requested to rate the **overall fidelity** of music. The term overall fidelity refers to the dynamics of the music and the definition provided to participants was: 'The dynamics and range of the music is not constrained or narrow'. Participants' perception of the overall fidelity of music with and without NFC is displayed in Figure 5-29.

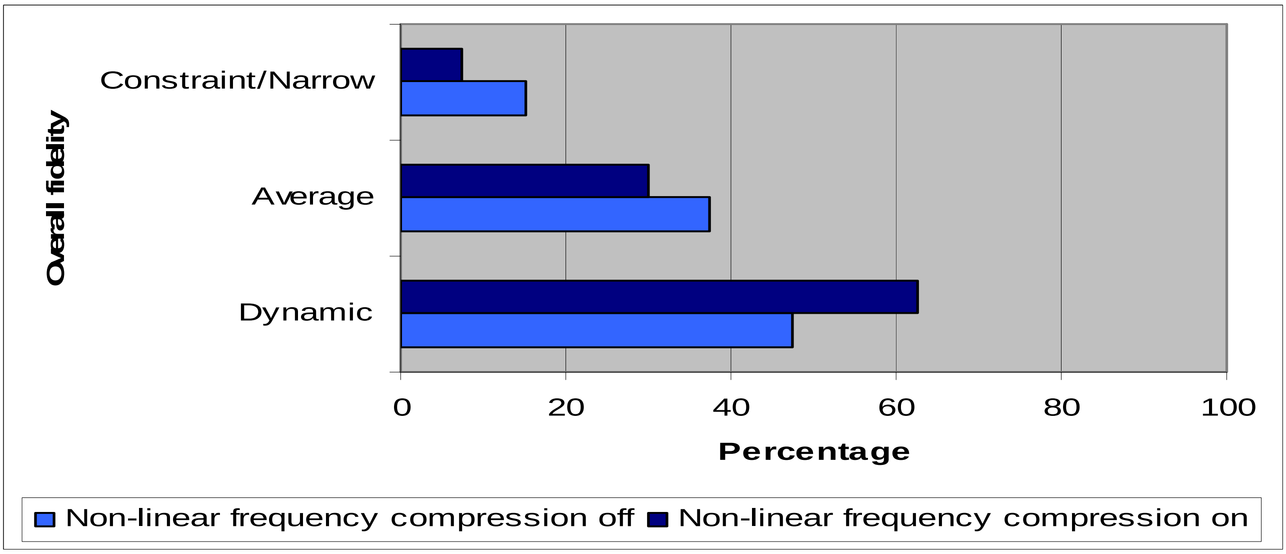

Figure 5-29: Participants' perception of the overall fidelity of music with non-linear frequency compression off versus non-linear frequency compression on

In Figure 5-29 it is clear that more participants (62.5% or n=25) described music as sounding dynamic with NFC on, compared to NFC off (47.5% or n=19). With NFC on, only 7.5% (n=3) of the participants indicated that music sounded constrained or narrow as opposed to 15% (n=6) when NFC was off. The overall fidelity of music was found to be of average quality by 30% (n=12) of the participants with NFC on and by 37.5% (n=15) of the participants with NFC off. The more dynamic quality of music obtained with NFC active was statistically significant (p=0.04).

For the purpose of this study, **tinniness** was defined as: 'Hearing the quality of tin or metal, a sense of cheap, low quality sound.' Participants' perceptions of the tinniness of music with the different NFC settings are displayed in Figure 5-30.

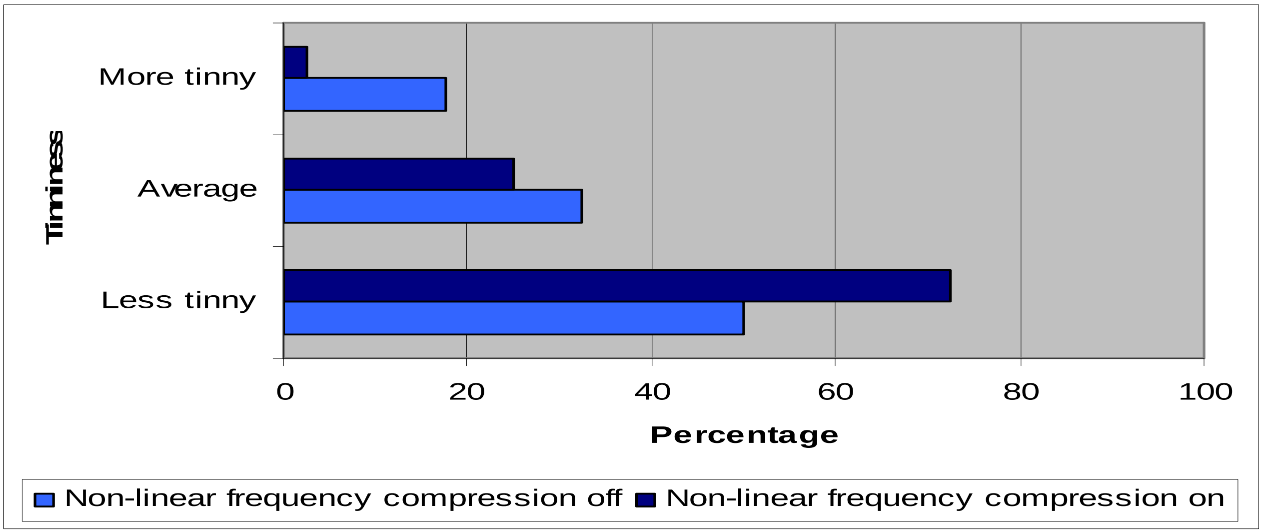

Figure 5-30: Participants' perception of the tinniness of music with non-linear frequency compression off versus non-linear frequency compression on

A statistically significant benefit (p=0.01) with the activation of NFC was obtained with regards to the tinniness of music since most participants found music to sound less tinny with NFC on (72.5% or n=29) compared to with NFC off (50% or n=20). With NFC on, 25% (n=10) of the participants indicated that the quality was average and one participant described the music as sounding tinny or giving a sense of a low quality sound. With the NFC algorithm off, 32.5% (n=13) of the participants rated the quality as average and 17.5% (n=7) found it to be more tinny and representative of a low quality sound.

Participants were also asked to rate the musical quality of **reverberance** as displayed in Figure 5-31. This term was defined as: 'The persistence of sound after the original sound is removed, a series of echoes.'

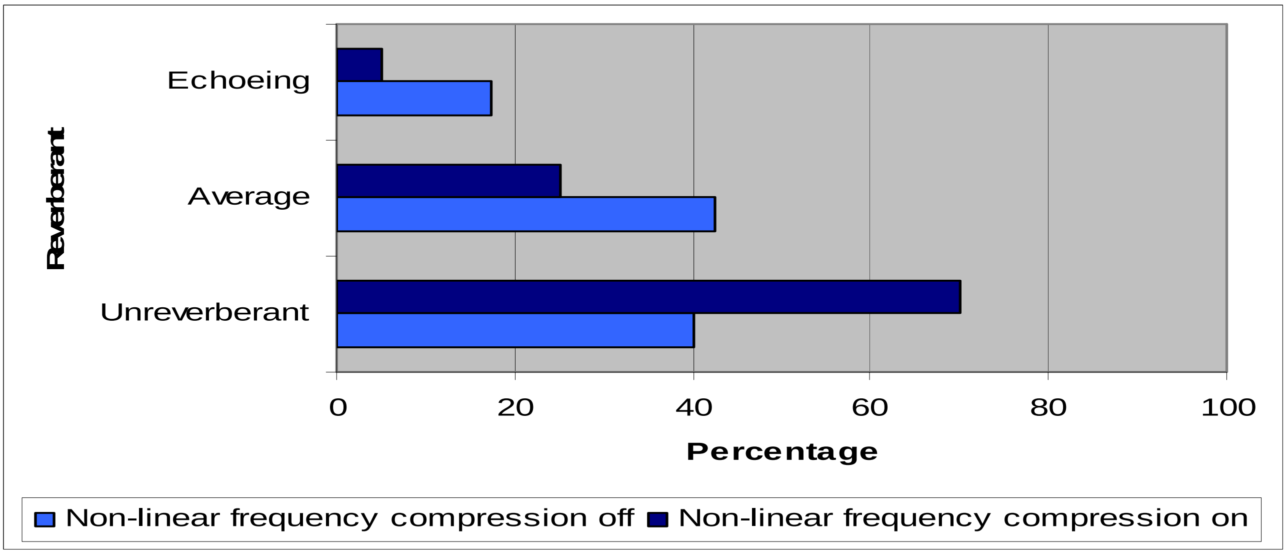

Figure 5-31: Participants' perception of the reverberance of music with non-linear frequency compression off versus non-linear frequency compression on

Again the ratings for NFC active were more positive than those obtained with NFC inactive and resulted in participants experiencing a statistically significant benefit (p=0.005) with regards to the reverberant quality of music with NFC active. Seventy percent (n=28) of the participants indicated that the quality of music was not reverberant, 25% (n=10) that the sound quality in terms of reverberance was average and 5% (n=2) of the participants complained about hearing echoes when listening to music with the NFC algorithm active. With NFC inactive, 40% (n=16) of the participants heard no echoes, 42.5% (n=17) of participants rated it as average and 17.5% (n=7) complained of the persistence of sound after the original sound was removed or reported hearing a series of echoes.

Hearing aid users frequently complain that they have forgone a formerly enjoyable aspect of their lives as they could no longer enjoy music to the same extent as before their hearing loss (Leek *et al.*, 2008:520). To determine how hearing aid users in the present study enjoyed music, they were asked to rate the **pleasantness** of music. Pleasantness of music refers to a feeling of enjoyment or satisfaction, as opposed to an annoying or irritating feeling. These results are visually presented in Figure 5-32.

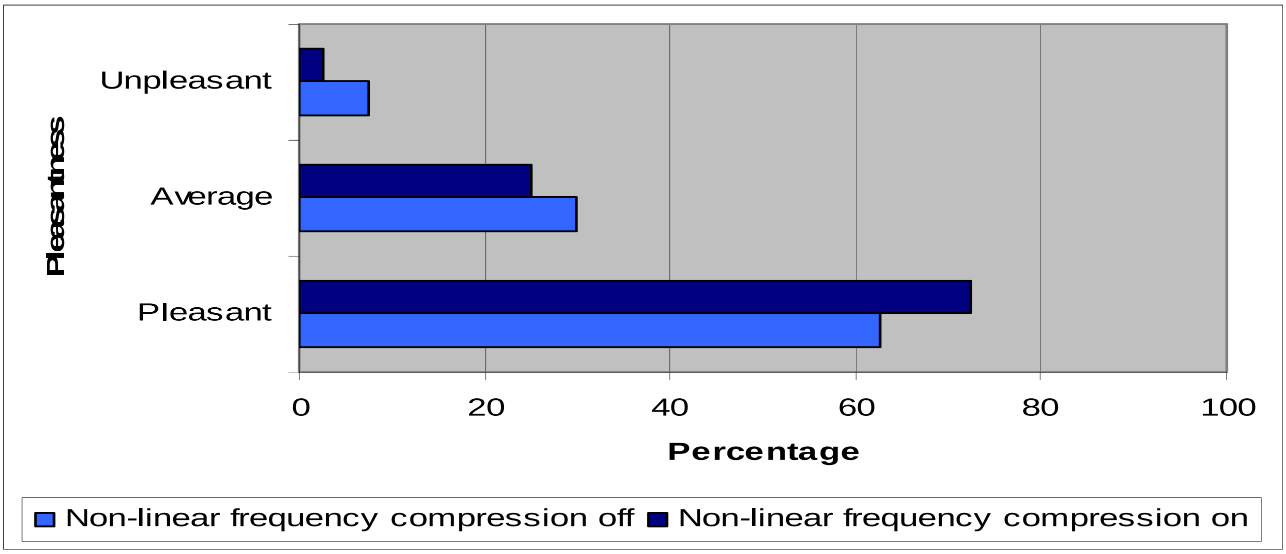

Figure 5-32: Participants' perception of the pleasantness of music with non-linear frequency compression off versus non-linear frequency compression on

Overall, the pleasantness of music was rated more positively with NFC on than with NFC off although this benefit was not statistically significant (p=0.13). With NFC on, 72.5% (n=29) of the participants indicated that the music sounded pleasant, 25% (n=10) indicated that it was of an average quality and only one participant found it to be annoying and irritating. When NFC was off, 7.5% (n=3) of the participants felt the music was annoying and irritating, 30% (n=12) rated it as average and 62.5% (n=25) felt it was enjoyable.

Participants' ability to discriminate between different musical instruments, distinguish between high and low notes, as well as discriminate the lyrics in a song or musical piece was also assessed. The relevant data is displayed in Figure 5-33.

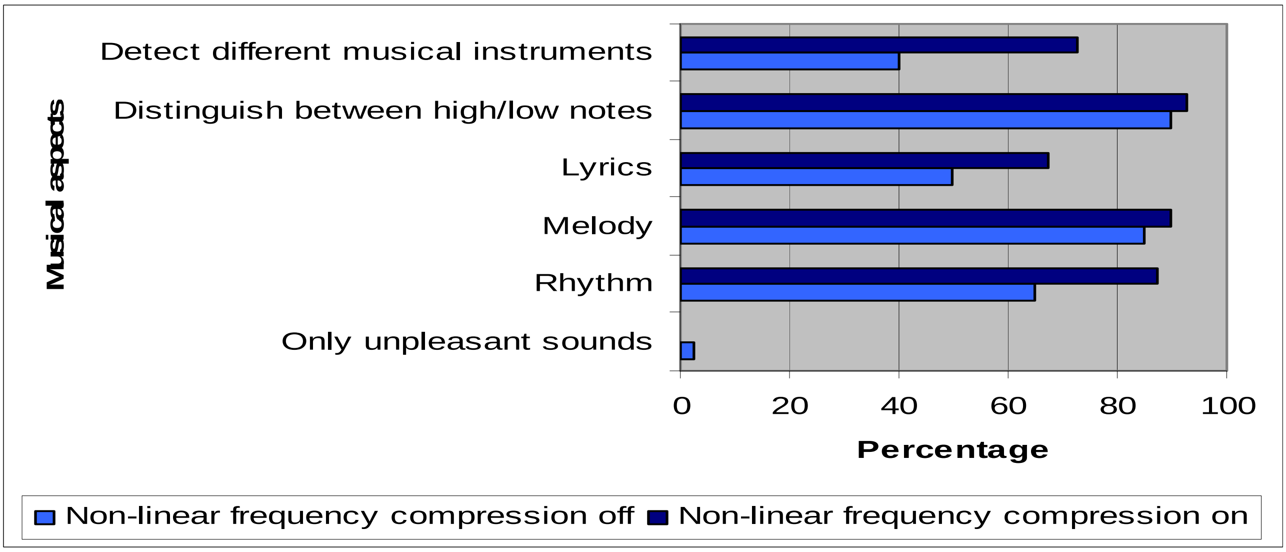

Figure 5-33: Participants' ability to discriminate between different musical aspects with non-linear frequency compression off versus non-linear frequency compression on

When considering the data displayed in Figure 5-33, it seems that participants were able to discriminate more positively between various different musical aspects with NFC on as opposed to NFC off. With the activation of NFC the only statistically significant benefit was obtained for participants' ability to detect different musical instruments (p=0.003) and discriminate the rhythm (p=0.015) in a musical piece. Although slight benefits with the activation of NFC was observed for participants' ability to distinguish between high and low notes (p=0.18), discriminate the lyrics (p=0.09) and melody (p=0.28) in a song, this benefit was not statistically significant. Only one participant indicated that he/she could only hear unpleasant sounds when listening to music – this was with the NFC algorithm inactive.

5.2.8 The effect of extended use of non-linear frequency compression and acclimatization on music perception (Sub-aim 7)

Since the early 1990s researchers are interested in the course of changes over time in performance associated with the use of hearing aids, referred to as acclimatization of hearing aid benefit (Humes, Wilson, Barlow & Garner, 2002:772). There are many as yet unexplored variables that may affect adaptation to hearing aid loudness and sound quality. Potential variables may include degree and configuration of hearing loss, interaction between degree/configuration of hearing loss and the fitting formula employed, duration of hearing loss, age and personality type (Lindley, 1999:57). The current study investigated the effect of extended use of NFC on music perception.

Nine participants were again assessed with the adapted version of the MPT which was also used in Phase 2, this time in order to determine what the effect of extended use of NFC and acclimatization was on their ability to perceive rhythm, timbre, pitch and melody. A summary of these results, compared to the results of their initial NFC assessment, is displayed in Figure 5-34.

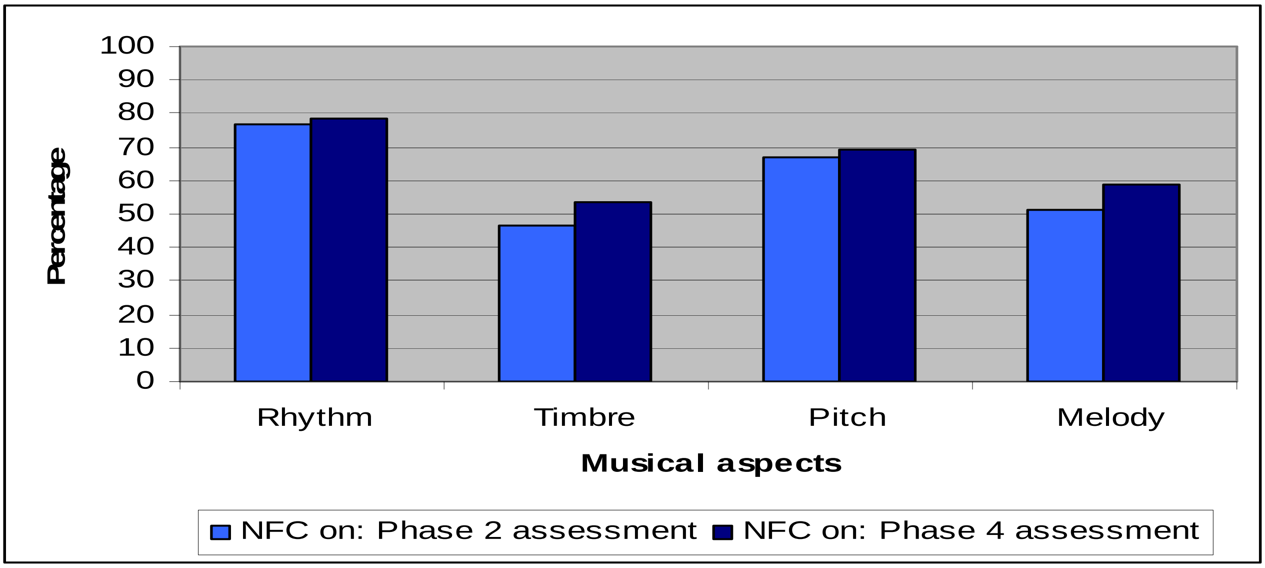

Figure 5-34 Participants' scores for the rhythm, timbre, pitch and melody sections of the Music Perception Test with non-linear frequency compression on during the assessments in Phase 2 and Phase 4

Figure 5-34 shows that there was a slight increase in participants' scores for all four sections of the MPT for the evaluation in Phase 4 compared to the evaluation in Phase 2. The smallest increase in average score was seen for the rhythm section of the test where participants' scores increased with only 1.8% on average, followed by the pitch section where the average score increase was 2.7%. A score increase of 6.6% was seen for the timbre section while the highest increase occurred for the melody section where participants scored on average 7.6% higher during the evaluation in Phase 4. To determine whether these increases in performance were statistically significant, the 'Analysis of variance' (ANOVA) test was used. The ANOVA can be used for the analysis of two means and is often applied to provide answers to complex designs such as the comparisons between treatment effectiveness of different approaches or the performance of several groups on a particular dependent variable (Maxwell & Satake, 2006:343). Therefore, this test was suitable for use in the current sub-aim in order to establish whether the extended use of NFC resulted in improved perception of music. Data obtained through this statistical procedure is displayed in Table 5-10.

Table 5-10: Descriptive inferential statistical values for extended use of non-linear frequency compression – objective assessment

DESCRIPTIVE		FIRST ASSESSMENT (PHASE 2)	SECOND ASSESSMENT (PHASE 4)
Rhythm (Section A)	Minimum	60%	60%
	Maximum	100%	100%
	Mean	76.89%	78.67%
	Standard deviation	8.79%	9.14%
	p-value	0.68	
Timbre (Section B)	Minimum	12%	38%
	Maximum	71%	71%
	Mean	46.82%	53.4%
	Standard deviation	17.26%	11.72%
	p-value	0.36	
Pitch (Section C)	Minimum	50%	50%
	Maximum	90%	100%
	Mean	66.67%	69.44%
	Standard deviation	12.25%	12.86%
	p-value	0.65	
Melody (Section 4)	Minimum	30.6%	40.7%
	Maximum	73.0%	83.3%
	Mean	51.32%	58.92%
	Standard deviation	12.57%	12.59%
	p-value	0.22	

The information in Table 5-10 confirms that the additional benefit obtained with the extended use of non-linear frequency compression was not significant for any of the areas described above.

To assess participants' subjective impression of music perception with the extended use of NFC, they were again asked to complete Questionnaire 2. The data is reflected in Figure 5-35.

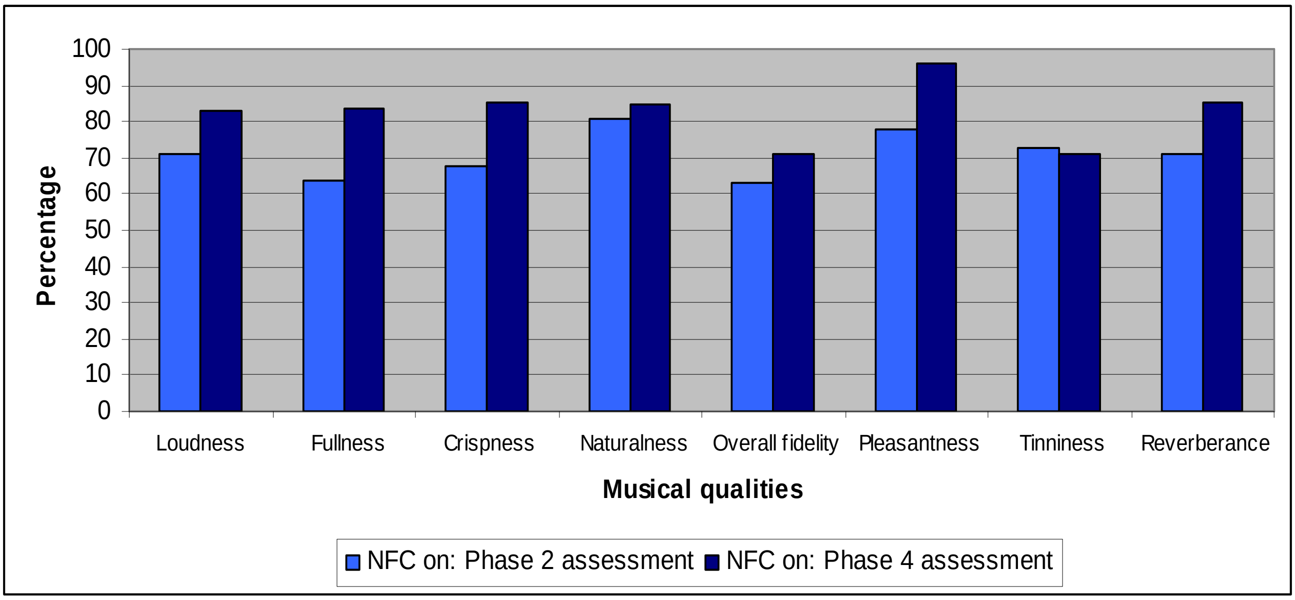

Figure 5-35: Participants' score for the different musical qualities assessed in Questionnaire 2 with non-linear frequency compression on during the assessments in Phase 2 and Phase 4

From Figure 5-35 it is clear that participants' perception of all the different qualities of music improved with extended use of NFC except for their perception of tinniness, which decreased with 1.7%. Participants rated the fullness (increased with 20%) of music as the musical quality that improved most with extended use of NFC, followed by the pleasantness (increased with 17.8%) and crispness (increased with 17.3%) of music. The other qualities that showed perceptual improvement after three months of using NFC were reverberance (increased with 14.1%) and loudness (increased with 12.1%) of music. Music qualities that had the least perceptual improvement with extended use of NFC were the overall fidelity and naturalness of music. Participants experienced a 6% improvement in the overall fidelity of music and a 3.8% improvement in the naturalness of music after they used the NFC technology for three months.

The ANOVA test was used again to determine whether these perceptual improvements were of statistical significance, as noted in Table 5-11.

Table 5-11: Descriptive inferential statistical values for extended use of non-linear frequency compression – subjective assessment

DESCRIPTIVE		FIRST ASSESSMENT (PHASE 2)	SECOND ASSESSMENT (PHASE 4)
Loudness	Minimum	60%	70%
	Maximum	85%	95%
	Mean	71%	83.1%
	Standard deviation	8.62%	8.96%
	p-value	0.01*	
Fullness	Minimum	55%	74%
	Maximum	72%	94%
	Mean	63.78%	83.78%
	Standard deviation	5.47%	6.32%
	p-value	0.00*	
Crispness	Minimum	60%	77%
	Maximum	75%	95%
	Mean	67.67%	85%
	Standard deviation	4.66%	5.2%
	p-value	0.00*	
Naturalness	Minimum	75%	78%
	Maximum	88%	92%
	Mean	80.89%	84.67%
	Standard deviation	4.01%	4.74%
	p-value	0.09	
Overall fidelity	Minimum	55%	60%
	Maximum	70%	80%
	Mean	63.22%	71.22%
	Standard deviation	4.47%	6.3%
	p-value	0.00*	
Pleasantness	Minimum	65%	88%
	Maximum	95%	100%
	Mean	78%	95.78%
	Standard deviation	9.39%	4.52%
	p-value	0.00*	
Tinniness	Minimum	60%	60%
	Maximum	83%	80%
	Mean	72.78%	70.56%
	Standard deviation	7.95%	7.68%
	p-value	0.56	
Reverberance	Minimum	60%	70%
	Maximum	80%	95%
	Mean	70.89%	85%
	Standard deviation	6.94%	7.65%
	p-value	0.00*	

***Statistically significant benefit**

The data displayed in Table 5-11 confirms that, with extended use of NFC, participants experienced a significant improvement in the loudness, fullness, crispness, overall fidelity, pleasantness and reverberant quality of music.

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

The main aim of this study was to determine the influence of non-linear frequency compression on the perception of music by adults presenting with a moderate to severe hearing loss. Through the discussion of the different sub-aims the researcher was able to realize this aim. A summary of previously discussed data are displayed in Figure 5-36 and Figure 5-37 in order to conclude on the influence of non-linear frequency compression on the perception of music.

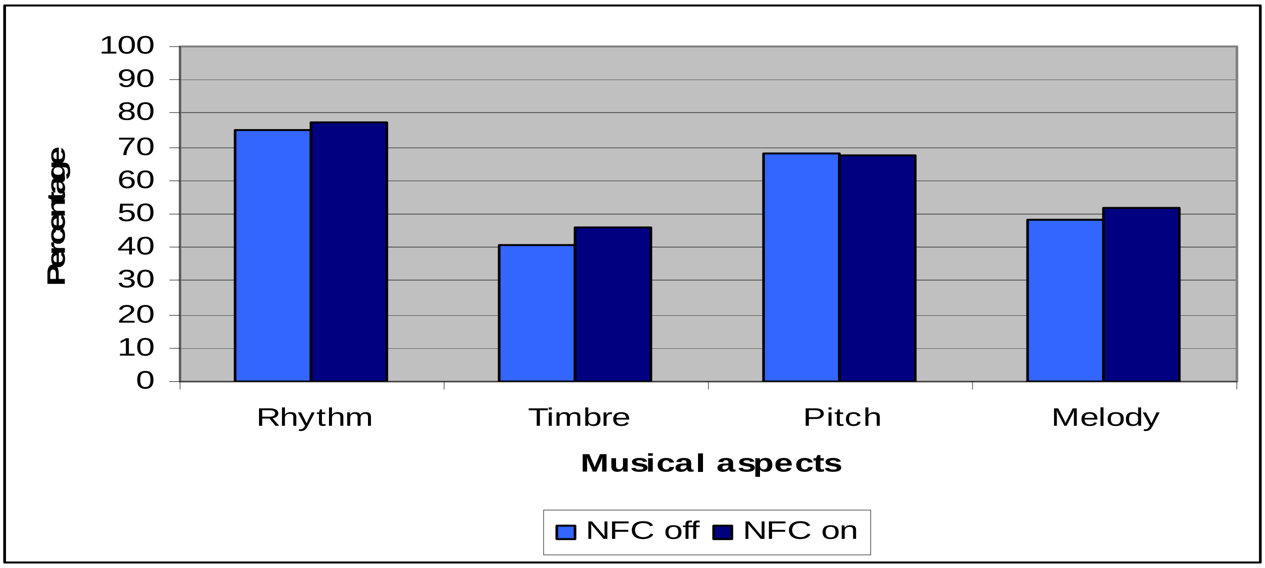

Figure 5-36: Participants' mean scores for the rhythm, timbre, pitch and melody of the Music Perception Test with non-linear frequency compression off and non-linear frequency compression on

As can be seen from Figure 5-36, participants perceived rhythm (2.4% increase), timbre (5.7% increase) and melody (3.4% increase) slightly better with NFC active compared to inactive, while almost identical scores were obtained for the perception of pitch (0.5% decrease). In terms of statistical significance, results were mixed; only the benefit for the perception of timbre (p=0.01) and melody (p=0.04) were found to be statistically significant. Participants' increased performance for the perception of rhythm were just not significant (p=0.06), while the slight decrease in the perception of pitch with the activation of NFC resulted in this relationship not being statistical significant (p=0.4).

A summary of the subjective assessment of participants' perception of listening to music with and without NFC is presented Figure 5-37.

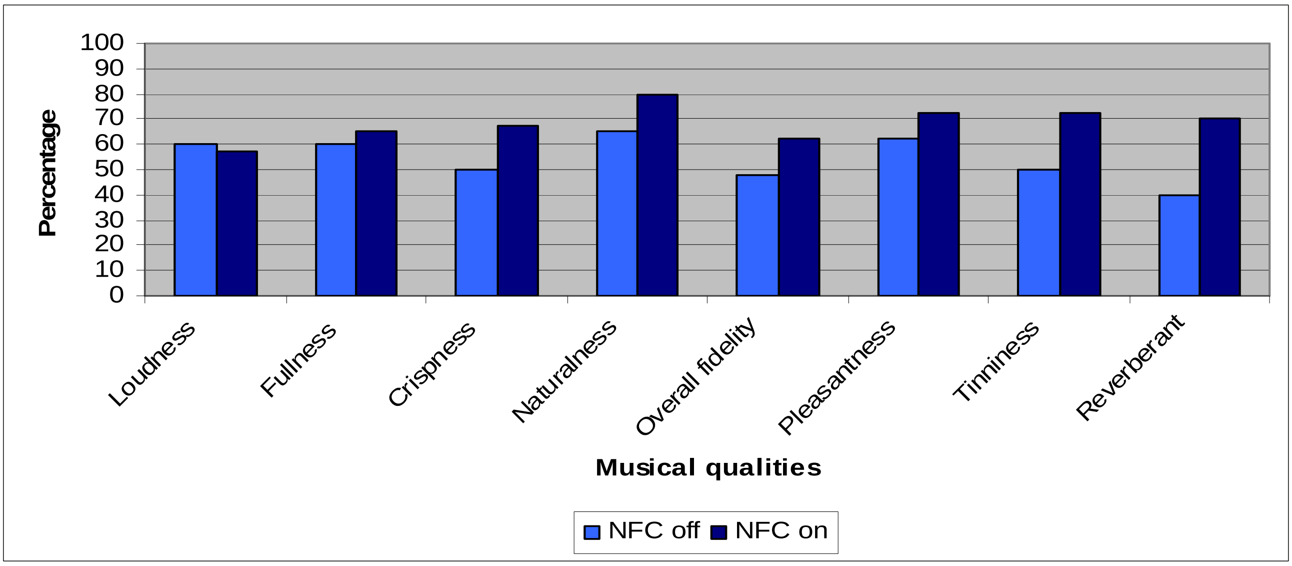

Figure 5-37: Participants' mean scores for the different musical qualities assessed in Questionnaire 2 with non-linear frequency compression off and on

According to Figure 5-37 it seems that participants preferred the NFC active setting for all perceptual music qualities except loudness. The results of statistical analysis of these observations were however mixed, since only the perceived benefit for overall fidelity (p=0.04), tinniness (p=0.01) and reverberance (p=0.005) were statistically significant. Although participants perceived naturalness (p=0.09), fullness (p=0.31), crispness (p=0.11) and pleasantness (p=0.13) of music as slightly better with NFC, these benefits were not significant.

When considering these results, one should however ask oneself what the influence of the participants' degree of hearing loss, slope of hearing loss and gender might have been on the data obtained. Tables 5-12 and 5-13 present the different degrees of hearing loss and how they affected the results. In Table 5-12, the effect of the mid frequencies (thresholds calculated at 1 kHz and 2 kHz) on the results were calculated, while Table 5-13 provides information regarding the effect of the high frequencies (thresholds calculated at 4 kHz and 8 kHz) on the data. The ANOVA test was again used to determine whether participants' degree of hearing loss significantly influenced the results of the MPT.

Table 5-12: Descriptive inferential statistical values to determine whether the degree of hearing loss (mid frequencies) influenced results of the Music Perception Test

DESCRIPTION		MID FREQUENCY REGION: NFC OFF			MID FREQUENCY REGION: NFC ON		
Test item	Degree of hearing loss	Mean	Std. Deviation	p-value	Mean	Std. Deviation	p-value
1 Rhythm identification	Moderate	91.25	13.29	0.060	92.50	8.66	0.019*
	Moderately severe	82.61	17.97		79.55	19.52	
	Severe	87.08	16.37		89.58	15.46	
2 Rhythm discrimination	Moderate	88.75	11.16	0.023*	88.33	10.30	0.353
	Moderately severe	80.11	14.97		84.77	8.76	
	Severe	75.83	25.92		82.08	17.69	
3 Rhythm recognition	Moderate	82.50	9.44	0.011*	84.17	9.003	0.017*
	Moderately severe	75.91	14.83		76.82	15.37	
	Severe	71.25	17.21		69.58	14.89	
4 Rhythm perception	Moderate	67.50	27.70	0.774	66.67	29.95	0.935
	Moderately severe	64.09	21.26		65.23	19.23	
	Severe	63.33	26.36		63.75	26.51	
5a Single instrument identification	Moderate	74.25	17.68	0.092	76.80	17.99	0.243
	Moderately severe	63.94	19.80		65.72	19.71	
	Severe	64.73	23.42		67.40	21.71	
5b Multiple instrument identification	Moderate	24.89	15.55	0.314	26.05	17.26	0.723
	Moderately severe	17.11	20.51		20.00	24.47	
	Severe	19.36	27.51		19.47	28.29	
6 Number of instruments	Moderate	58.54	17.89	0.001*	59.67	18.43	0.134
	Moderately severe	45.98	18.56		50.30	19.21	
	Severe	37.73	26.24		44.46	25.61	
7 Pitch identification	Moderate	81.67	13.41	0.015*	83.33	13.71	0.046*
	Moderately severe	72.50	19.07		71.14	19.20	
	Severe	67.92	20.10		66.25	21.23	
8. Pitch discrimination	Moderate	66.67	13.08	0.033*	64.17	14.43	0.003*
	Moderately severe	63.64	13.15		67.50	12.41	
	Severe	58.33	15.89		54.17	19.09	
9. Musicality perception	Moderate	53.33	24.26	0.553	54.17	26.10	0.437
	Moderately severe	48.41	17.61		50.00	17.52	
	Severe	48.75	21.70		45.42	20.85	
10. Melody identification	Moderate	56.02	25.38	0.015*	64.10	20.46	0.006*
	Moderately severe	49.68	19.43		54.45	16.73	
	Severe	41.14	23.32		41.58	23.89	
11. Music-in-noise song identification	Moderate	65.31	30.97	0.035*	70.95	31.40	0.175
	Moderately severe	53.80	38.17		55.39	39.04	
	Severe	41.74	38.74		45.57	39.45	

***Statistically significant benefit**

In order to fully comprehend the information displayed in the Table 5-12 it is important to understand that the degrees of hearing loss were stipulated as:

- Moderate (thresholds of 41 dB to 55 dB)
- Moderately severe (thresholds of 56 dB to 70 dB)
- Severe (thresholds of 71 dB to 90 dB)
- Profound (thresholds above 90 dB)

As can be seen from Table 5-12, the degree of hearing loss at the mid frequencies had a significant influence on participants' performance for the rhythm recognition (NFC off: p=0.011; NFC on: p=0.017), pitch identification (NFC off: p=0.015; NFC on: p=0.046), pitch discrimination (NFC off: p=0.033; NFC on: p=0.003) and melody identification (NFC off: p=0.015; NFC on: p=0.006) tasks. With NFC inactive, the degree of hearing loss at the mid frequencies also influenced the rhythm discrimination (p=0.023), number of instruments (p=0.001) and music-in-noise song identification (p=0.035) tasks significantly. This was however not observed with the activation of NFC and warrants further investigation. For all these sub-tests it seemed that participants with a less severe hearing loss at the mid frequency region obtained higher scores than participants with a more severe hearing loss and that performance decreased with increased thresholds.

Table 5-13 provides statistical information regarding the effect of the high frequencies (thresholds calculated at 4 kHz and 8 kHz) on participants' performance on the MPT.

Table 5-13: Descriptive inferential statistical values to determine whether the degree of hearing loss (high frequencies) influenced results of the MPT

DESCRIPTION		HIGH FREQUENCY REGION NFC OFF			HIGH FREQUENCY REGION NFC ON		
Test item	Degree of hearing loss	Mean	Std. Deviation	p-value	Mean	Std. Deviation	p-value
1 Rhythm identification	Moderate	100.00	0.00	0.511	100.00	-	0.366
	Moderately severe	84.06	17.01		78.13	19.05	
	Severe	86.52	18.27		85.45	19.70	
	Profound	84.00	15.97		86.33	14.74	

DESCRIPTION		HIGH FREQUENCY REGION NFC OFF			HIGH FREQUENCY REGION NFC ON		
Test item	Degree of hearing loss	Mean	Std. Deviation	p-value	Mean	Std. Deviation	p-value
2 Rhythm discrimination	Moderate	85.00	7.07	0.006*	80.00	-	0.807
	Moderately severe	82.19	13.13		83.13	7.04	
	Severe	85.00	13.27		86.06	10.88	
	Profound	73.50	24.83		83.67	15.86	
3 Rhythm recognition	Moderate	85.00	7.07	0.813	90.00	-	0.787
	Moderately severe	74.38	13.90		74.38	13.65	
	Severe	75.76	16.08		75.45	18.56	
	Profound	75.50	15.45		76.33	11.59	
4 Rhythm perception	Moderate	100.00	0.00	0.104	100.00	-	0.100
	Moderately severe	60.94	21.46		55.63	20.65	
	Severe	66.67	25.20		69.39	24.10	
	Profound	62.50	22.89		64.00	21.75	
5a Single instrument identification	Moderate	93.75	8.84	0.155	100.00	-	0.026*
	Moderately severe	61.77	18.61		56.33	19.40	
	Severe	67.39	19.34		68.95	20.10	
	Profound	65.06	23.20		71.82	18.60	
5b Multiple instrument identification	Moderate	46.90	4.38	0.007*	50.00	-	0.121
	Moderately severe	22.56	19.63		21.67	20.86	
	Severe	22.69	24.35		26.17	28.47	
	Profound	11.98	19.55		13.31	20.24	
6 Number of instruments	Moderate	75.00	0.00	0.001*	75.00	-	0.071
	Moderately severe	44.78	19.89		44.88	19.35	
	Severe	51.61	22.36		56.36	22.87	
	Profound	37.88	20.27		44.77	19.33	
7 Pitch identification	Moderate	95.00	7.07	0.199	100.00	-	0.496
	Moderately severe	71.56	17.06		68.75	17.84	
	Severe	74.55	18.74		71.52	20.02	
	Profound	70.00	20.25		72.00	20.41	
8 Pitch discrimination	Moderate	70.00	0.00	0.453	70.00	-	0.278
	Moderately severe	64.06	11.88		68.75	10.88	
	Severe	63.48	13.87		63.33	14.51	
	Profound	60.33	15.84		59.33	19.11	
9 Musicality perception	Moderate	80.00	0.00	0.042*	80.00	-	0.193
	Moderately severe	54.06	15.21		55.63	15.04	
	Severe	48.79	21.95		46.97	21.72	
	Profound	46.17	19.05		47.33	19.46	
10 Melody identification	Moderate	95.00	7.07	0.00*	100.00	-	0.017*
	Moderately severe	53.35	18.63		53.38	18.57	
	Severe	52.15	22.58		53.47	21.49	
	Profound	39.20	19.40		43.75	18.31	
11 Music-in-noise song identification	Moderate	100.00	0.00	0.305	100.00	-	0.624
	Moderately severe	48.28	36.66		49.43	34.72	
	Severe	50.91	37.99		53.99	39.63	
	Profound	53.34	38.66		56.98	39.98	

***Statistically significant benefit**

Table 5-13 confirms that the degree of hearing loss at the high frequencies significantly influenced participants' performance on the melody identification task (NFC off: p=0.00; NFC on: p=0.017). With NFC inactive, the degree of hearing loss at the high frequencies also had a significant influence on the rhythm discrimination (p=0.006), multiple instrument identification (p=0.007), number of instruments (p=0.001) and musicality perception (p=0.042) tasks, but none of these tasks were significantly influenced when NFC was activated. This may be explained by the fact that with the activation of NFC, the high frequency information were compressed to lower frequencies and therefore the high frequencies did not influence performance because participants depended on the lower and mid frequency regions for audibility. Again it seemed that participants with a less severe hearing loss showed increased performances on the different sub-tests when compared to participants with a more severe hearing loss.

In terms of the influence of the pattern of hearing loss on performance, it seemed that participants with a flat hearing loss scored significantly higher than participants with a sloping hearing loss on the number of instruments (NFC off: p=0.005; NFC on: p=0.044), musicality perception (NFC off: p=0.000; NFC on: p=0.036) and melody identification tasks (NFC off: p=0.000; NFC on: p=0.005). With NFC inactive, the pattern of hearing loss also significantly influenced the performance on the rhythm identification (p=0.05), rhythm discrimination (p=0.016), rhythm perception (p=0.018), multiple instrument identification (p=0.000) and music-in-noise song identification (p=0.044) tasks. This was not seen with NFC active and it can therefore again be explained by the fact that with a sloping hearing loss, more frequencies might undergo frequency compression than with a flat hearing loss. Furthermore, one expects that with a sloping hearing loss the amount of frequency compression will be more aggressive than with a flat hearing loss.

With regards to gender, it seemed that men performed significantly better than women on the pitch discrimination (p=0.000), musicality perception (p=0.052), melody identification (p=0.007) and music-in-noise song identification (p=0.000) tasks. No other significant differences in gender performance were observed.

Finally, the NFC cut-off frequency on the hearing aids as well as the data logging values for hearing aid use by participants should also be taken into account when reviewing the results. As mentioned previously, the NFC cut-off frequency refers to the point above which NFC is applied (McDermott, 2010:3). These data are displayed in Table 5-14.

Table 5-14: Non-linear frequency compression cut-off frequency for hearing aids

Participant	NFC (kHz)	Participant	NFC (kHz)	Participant	NFC (kHz)	Participant	NFC (kHz)
1	2.4	11	3.3	21	3.2	31	3.2
2	3.6	12	2.4	22	4	32	3.8
3	4	13	1.9	23	3.3	33	2.4
4	3.8	14	4	24	4	34	4
5	3.4	15	3.2	25	3.3	35	3.9
6	3.3	16	2.9	26	4	36	3.3
7	4	17	2.8	27	4	37	4
8	4	18	2.7	28	4	38	3
9	3.3	19	4	29	4	39	1.5
10	2.8	20	3.2	30	2.4	40	2.9

Table 5-14 indicates that for most participants the NFC cut-off frequency was left on the default value of the fitting software, except for two participants (participant 13 and 39).

The data logging values on the hearing aids give an indication of the average amount of time per day that participants wore the hearing aids. This information is displayed in Table 5-15.

Table 5-15: Data logging values for hearing aid use with non-linear frequency compression on versus non-linear frequency compression off

Participant	NFC ✔ (hours)	NFC ✖ (hours)	Participant	NFC ✔ (hours)	NFC ✖ (hours)	Participant	NFC ✔ (hours)	NFC ✖ (hours)
1	7	7	15	14	14	29	13	13
2	12	11	16	13	13	30	13	13
3	15	15	17	14	14	31	13	14
4	8	9	18	8	9	32	15	15
5	15	15	19	9	9	33	17	15
6	9	8	20	13	14	34	7	7
7	8	7	21	13	15	35	9	8
8	7	7	22	10	10	36	10	10
9	8	8	23	14	13	37	14	11
10	6	5	24	9	10	38	10	10
11	16	15	25	13	9	39	4	4
12	14	14	26	9	9	40	16	15
13	16	15	27	17	15			
14	16	16	28	11	11			

✔ Non-linear frequency compression on **✖ Non-linear frequency compression off**

As can be seen from Table 5-15, there are no real differences in the amount of time that participants wore the hearing aids with NFC active versus NFC being inactive.

5.3 CONCLUSION

As critical as it is to measure the benefits of hearing aid intervention at the level of the patient, the measurement of treatment outcomes is gaining greater importance at the national health care stage (Valente, 2006:36). Through the routine use of clinically applied outcome measures and carefully controlled clinical trials, audiologists can lay a foundation for evidence-based clinical practice guidelines. Clinical practice guidelines, in turn, minimize variability in outcome, maximize treatment efficacy, reduce risks, decrease waste, improve patient satisfaction, and should elevate the profession of Audiology among third party payers, other health care providers and, most importantly, current and future patients. As audiologists continue to compete in the health care marketplace, they have to demonstrate that their intervention reduces activity limitations, decreases participation restrictions, and improves health-related quality of life. Only by measuring the outcomes of intervention can audiologists be assured that intervention does make a difference and that patients do benefit form their care.

This study presents scientific results which indicate that non-linear frequency compression does in some cases contribute to a significant benefit in the objective assessment of the perception of music. In cases where the benefit was not found to be of statistical significance, no significant decrease in performance was seen. Furthermore, it became clear that participants demonstrated a subjective preference for listening to music with non-linear frequency compression; they indicated that they were better able to detect different musical instruments, distinguish between high and low notes and hear the melody, rhythm and lyrics in a song than when listening without non-linear frequency compression. The influence of non-linear frequency compression in the music perception of adults with a moderate to severe hearing loss, however, warrants further investigation to determine whether greater benefits for music perception will be achieved with extended use of this technology.

5.4 SUMMARY

This chapter provided a presentation of the results from the research study which included data from objective and subjective evaluations. Furthermore, findings regarding music perception and acclimatization to non-linear frequency compression hearing aids were presented. Results were organized according to the sub-aims and how they related to the main aim. The presented results established the platform for the discussion that follows in Chapter 6.

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 rhythm identification, rhythm recognition and rhythm perception 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 rhythm discrimination 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 <u>number of instruments</u> 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.

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

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 musicality perception 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.

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[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.

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

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.

Chapter 7

CONCLUSION AND RECOMMENDATIONS

Chapter aim: The aim of this chapter is to clarify the conclusions drawn from the results of this research project, critically evaluate the findings and formulate recommendations for future research.

7.1 INTRODUCTION

The hearing industry has made great strides towards providing effective solutions for people with hearing loss. It seems, however, that an important group of people with a hearing loss, namely musicians and music lovers with a hearing loss, has been neglected and denied easy access to already existing technology that could effectively address their needs (Chasin & Revit, 2009:10).

Audiologists need to improve their service to performing musicians and other people who wish music to be part of their lives (Chasin, 2010:27). Musicians count on audiologists for successfully practicing their profession and music lovers for the improvement of their quality of life. Over the last few years more information regarding music perception with hearing aids and different hearing aid technologies has become available. It is every audiologist's responsibility to continuously gain new information about new hearing aid technologies as well as fitting preferences and to share this information. If audiologists can realize the above, they will have reached a new level of success in their profession (Chasin & Revit, 2009:10).

Previously, the inherent technical challenges of hearing aids limited audiologists' potential to succeed. This is no longer the case (Chasin & Revit, 2009:10). As audiologists develop the technology and skills to serve music loving listeners, all clients may benefit from hearing aids. In order to provide some information regarding the efficacy of non-linear frequency compression, this study aimed to determine the influence of this signal processing strategy on the perception of music in adults presenting with a moderate to severe hearing loss. The purpose of this chapter is to formulate conclusions based on the results discussed in Chapter 6 and to discuss its implications. A critical evaluation of the study, followed by recommendations for future research, concludes this chapter.

7.2 CONCLUSIONS

Music differs dramatically from speech and is therefore a potential challenge for hearing aid fittings (Hockley *et al.*, 2010:38). Assessments of music perception with amplification devices like hearing aids are important, since most people listen to music for personal pleasure and enjoyment and therefore need to be able to hear music in order for music to be part of their lives and improve their life quality. For this reason music perception was used to measure the efficacy of non-linear frequency compression in adults with a moderate to severe hearing loss, and to provide some indication of the efficiency of this type of technology. These outcomes can be summarized as follow:

- The MPT served as a reliable data acquisition instrument for determining the influence of NFC on music perception.
- Results of the present study indicate that the benefit obtained with the activation of NFC for the perception of rhythm was just short of significant.
- Participants obtained a statistically significant benefit with the activation of NFC in the perception of timbre.
- Hearing aid users did not experience a clear advantage or disadvantage with the use of NFC when performing pitch tasks.
- A statistical significant improvement in the perception of melodies was experienced by participants when NFC was activated.
- Subjectively participants rated music more positively with NFC, which implies that, with the activation of NFC, participants found music to sound fuller, clear and distinct, natural, less constrained or narrow, less tinny, without echoes and therefore sounding more pleasant.
- Slight improvements in participants' performance on the MPT was seen after using NFC for an extended period of time, which is an objective indication that they may perceive rhythm, timbre, pitch and melody better after extended use of this algorithm.

- When asked to subjectively rate music after the extended use of NFC, participants indicated that music sounded fuller, crisper, more natural and pleasant than earlier. They also indicated an improvement in the loudness of musical stimuli, heard less echoes when listening to music, found music more dynamic and less constrained. The only quality not to have improved after the extended acclimatization period was the perceived tinny quality of music, which participants rated very similar to their initial assessment.

From the discussion above, it is clear that objective and subjective music perception assessments confirmed that hearing aid users benefit from NFC when listening to music and that this algorithm does not influence the perception of music negatively. It further seems that hearing aid users with a more severe hearing loss in the mid and high frequencies as well as hearing aid users with a sloping hearing loss benefitted even more from the application of NFC when listening to music.

The above results warrant a trial period with NFC hearing aids combined with regular music perception assessments for every music loving adult with a moderate to severe hearing loss in order to obtain more scientific data and thereby improve the quality of audiological services to these persons.

7.3 CLINICAL IMPLICATIONS

Clinically the findings above first of all indicate that the MPT can successfully be used as an evaluation tool to assess music perception in hearing aid users. Using a test like this in the hearing aid industry may result in more accountable hearing aid fittings, specifically focusing on music perception. The test can further be used as a counseling tool to assist audiologists and their clients in understanding the problems they experience with music perception; it may also be used for music training in areas where audiologists experience problems in customizing individual fittings. In the current study the test was used to determine the influence of non-linear frequency compression on music perception, but in future the test may also be used to evaluate other algorithms and hearing aid functions to determine their influence on music processed by hearing aids.

Furthermore, it is evident that an accurate assessment of music perception requires that objective as well as subjective information be obtained from patients. Such information regarding different aspects of music renders insight into in the problems that hearing aid users experience when listening to music and will enable audiologists to better understand complaints by hearing aid users about listening to music. Listening to music gives rise to a large variety of experiences (Kreutz *et al.*, 2008:57) and therefore it is evident that each individual experiences music differently. It is therefore important to obtain a subjective music evaluation from each patient in order to adequately address individual difficulties.

The findings indicated that hearing aid users with a moderate to severe hearing loss demonstrated a clear preference to listen to music with NFC, as was confirmed by their increasingly improving performances in the objective evaluations. With this taken into account, the importance of providing the highest level of amplification technology that is financially attainable for music loving adults with a hearing loss cannot be ignored, especially if one takes into account that previous research also indicated benefits for the perception of speech with this technology.

Non-linear frequency compression technology in hearing aids may improve music perception for some adults with a hearing loss. It is evident, however, that significant individual differences come to the fore when music perception is investigated and therefore it may be necessary to individually confirm music perception benefits with NFC. The large inter-subject variability with regard to the performance on the various sub-tests warrants the individualization of fittings and consideration of each individual's unique experience of music. However, because the results of this study indicated that NFC is not disadvantageous for music perception, it cannot be dismissed as an option for individuals to increase music enjoyment. A trial fitting of the hearing aids for conducting assessments similar to the ones done in this study, but on individual adults, may determine the efficacy and efficiency of this type of technology for a specific adult.

7.4 CRITICAL EVALUATION OF THE RESEARCH

A reflection on the positive and negative aspects of this study is necessary in order to gain perspective on and insight into the music perception abilities of adults with a moderate to severe hearing loss using NFC technology.

The main **strength** of this study is that it attempts to provide evidence regarding the use of NFC in adults with a unique focus point. The main focus of current research on the use of frequency lowering, specifically NFC, in international studies is on speech-related matters; this study, however, provides information regarding the use of NFC and **different stimuli**, namely **music**. As there are to date no studies available on the subject of NFC and music perception, this study contributes towards knowledge in this field and assists audiologists to provide evidence-based services to their music loving clients. It also serves as background for future research.

Since the main aim of this study was to determine the influence of NFC on the perception of music by adults presenting with a moderate to severe hearing loss and no existing music perception test could be found in the literature to use as data-acquisition material, another contribution of this study was the **development of the MPT** for hearing aid users. After completion of the study, this test can be used as data-acquisition material in future hearing aid studies, especially within the South African context where a need for such a test currently exists.

The main focus of research on the use of NFC technology in international studies is on severe to profound hearing loss, specifically with known cochlear dead regions. Another strength of this study therefore is that it also provides information regarding the use of NFC in adults with **different configurations of hearing loss;** it was found that adults with a moderate to severe hearing loss may benefit from NFC, and if not, this algorithm will not be disadvantageous to their enjoyment of music.

Several other measures were taken throughout conducting this study to ensure a reliable outcome and thereby contribute to the strengths of the study. This includes the **single blinding** strategy that was applied in the research process that implied that only the researcher knew which group a participant was assigned to. Blinding is essential if subjective judgments such as questionnaires or rating scales are used as outcome data and may also be important for many objective tests (Cox, 2005:428). By not informing participants of the current settings of the hearing aids (NFC active or inactive), the reliability and validity of the results were improved. Furthermore, the researcher consulted with statisticians throughout the study and a **randomized schedule** for fitting participants with NFC was established using statistical programs. This was important, because the lack of randomization is another common weakness in amplification research (Cox, 2005:428). A **pilot study** was also conducted prior to the main study to determine the effectiveness of the MPT and questionnaires and to identify necessary changes to be made to these data acquisition materials. By including participants with a hearing loss in the pilot study, the validity and reliability of the results of the main study was improved (Maxwell & Satake, 2006:62). Another positive aspect of the research process is that sufficient time was provided for participants to **acclimatize** to the NFC technology as evaluations were only done after participants have been wearing the hearing aids for a period of four weeks (Stuermann, 2009:2).

Lastly, this study included **40 participants**. A minimum number of 30 participants were stipulated but the researcher aimed at including more than 30 participants to account for possible dropouts; Cox (2005:428) explains that not accounting for dropouts is one of the most common weaknesses in amplification research. In order to encourage participants to take part in the study, the researcher aimed to ensure that the MPT and questionnaires were **well structured and user friendly**. This contributed to the correct and appropriate completion of the documents and therefore provided valid and reliable data after completion and analysis (McMillan & Schumacher, 2006:210). Although questionnaires instead of personal interviews or focus groups were used to obtain subjective information from participants, there was a **100% return rate** for all the questionnaires, because participants were asked to complete them in the presence of the researcher and return it before leaving the premises. This is seen as an advantage, because a low response rate, as often found with mailed questionnaires, holds negative consequences for the quality of the research (Bless & Higson-Smith, 2000:109).

The main **weakness** of the study is that the researcher did not make use of the **TEN test** to diagnose cochlear dead regions. The results of a study by Vinay and Moore (2007:238), however, indicated that cochlear dead regions are rare for any frequency in the range from 500 Hz to 4 kHz when the audiometric threshold is 60 dB HL or better and, should the information be available directly from the audiogram, additional testing may be unnecessary (Summers, 2004:1423). Therefore, to avoid administering the TEN test unnecessarily, a useful rule to apply would be to test only when the audiometric threshold exceeds 60 dB HL at one or more frequencies (Vinay & Moore, 2007:232). Due to the severity of hearing loss presented by participants included in this study it was assumed that most participants had cochlear dead regions for at least the high frequencies.

Furthermore, it could be argued that more participants should be included in the study as the use of a **bigger sample** may improve the possibility of generalizing the results to the larger population. However, providing devices to participants on loan has always been a financial challenge to privately funded researchers. To date, no state funding has been made available for studies involving the provision of hearing aids to participants.

The lack of **double blinding** in the research design could also be viewed as a weakness of the study. The researcher did, however, implement a single blinding approach but could not implement double blinding due to the fact that only one audiologist was available for all the fittings and assessments. However, the researcher remained unbiased in her conduct throughout the study and avoided influencing participants' perceptions with the different hearing aid settings.

Lastly, to use the MPT effectively within the South African context, it should be performed on a larger sample that is **representative of the country's demographics**. When research is done with the aim of using a newly developed test and collecting normative data for such a test, participants of all ethnic groups should be included.

The final decision about the validity of the evidence produced by a particular study is made on the basis of a consideration of the inherent strengths of the research design and any weaknesses that could compromise the quality of execution (Cox, 2005:430). Although this study had certain limitations, it is obvious that several strategies were implemented to contribute to the strength and quality of the research design which ultimately lead to attaining accurate and valid results.

7.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Not only is the technology for music input still in its infancy, but the research and clinical knowledge and understanding of what music lovers need to hear are also still not fully established (Chasin & Russo, 2004:35). Based on the above and on the findings of this study, the following recommendations for future research are proposed:

- A similar study with a larger sample size may yield conclusive evidence regarding the efficacy of the use of the MPT as well as NFC for music perception and would increase the statistical power of the current research (Bentler & Duve, 2000:637).
- In the current study, one NFC signal was presented to both ears. The amount of NFC applied was calculated according to the thresholds of the better ear, but this is not ideal because it does not allow for asymmetrical hearing thresholds (Simpson *et al.*, 2005:291). Furthermore, the appropriate fitting of hearing aids remain unclear where the extent of dead regions differs across the ears; in this regard research has shown that, while subjects can learn to interpret frequency lowered information, it may be more difficult if the shift is mismatched across the two ears (Robinson *et al.*, 2007:307). It is arguable that more audibility (with a stronger NFC setting) could have been provided to the poorer ear. However, the alternative position is that symmetry in the frequency domain may prevent binaural integration of sound (Scollie *et al.*, 2008:7). Research should investigate adjustments to accommodate binaural hearing differences and investigate whether fittings will be improved or degraded with a more ear-specific strategy.
- It may be of value to determine the effect of NFC for specific music instruments since some musical instruments place more emphasis on high frequency information compared to others. NFC may, for instance, be beneficial to certain musicians, depending on the instrument they are playing, whilst for others it might not be.
- Further research is necessary to establish the role of age-related auditory plasticity when measuring benefit change scores, as well as other factors that may contribute to different rates of auditory acclimatization with NFC. In this regard Glista *et al.* (2009:643) indicate that a larger acclimatization effect may be associated with a more severe hearing loss.
- Adult-child differences with NFC should be investigated to determine if the fitting approach used for children and adults should be different. This may be the case because adults are able to extract some useful information from off-frequency listening as demonstrated by their ability to benefit from amplification up to one octave inside a dead region and normal adult listeners were found to rather quickly learn to make use of high frequency information that was shifted to lower frequencies (Munro, 2007:14).

- The alerting statistics on hearing loss emphasize the importance of further research in this field to better understand the influence of hearing loss on people's lives and to ensure optimal hearing aid use in all situations for these people. Furthermore, it was found that improving consistency of communication success (through amplification) narrows the discrepancy in stress levels experienced by people; a survey conducted in the New York Times showed that 64% of the general population listened to music to relax (Kuk & Peeters, 2008: par. 3). It therefore is incumbent upon health care professionals, including audiologists, to understand how music has an effect on the overall well-being of people. The above should encourage audiologists to do their best to ensure the consistent and comfortable use of music by people with a hearing loss for purposes of entertainment as well as for therapeutic benefits.

Obtaining scientific data regarding the abovementioned topics will elevate audiologists' clinical care of patients as well as elevate our profession, promote better fitting practices, result in greater patient satisfaction and eventually reduce the hearing aid return rate (Valente, 2006:33).

7.6 CLOSING STATEMENT

In the current approach to audiological management much focus is being placed on hearing aid technologies and fitting schemes. With rapid advances in component miniaturization and digital processing algorithms, there is an assumption that the majority of hearing losses can be managed and that all hearing aid related problems can be addressed (Bentler, 2006:89). With a reported 17% of return-for-credit rate for digital hearing aids and another 16% of aids in dresser drawers, it may be time to abandon the assumption that most users can't hear the difference in bandwidth, response smoothness, time constants, and overload for high-level sounds (Killon, 2009:30) and to discard the notion that hearing aid wearers should be satisfied with their hearing aids in all listening situations, including the enjoyment of music, even though audiologists do not have scientific data on which fittings can be based. Therefore, it is hoped that hearing aids will soon offer considerably improved accessibility for listening to music and that this study contributes to a better understanding of listening to music so that every person with a hearing aid will be able to conclude with the words of this famous song:

(Retrieved from http://www.lyricsfreak.com/a/abba/thank+you+for+the+music_20002662.html)

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APPENDIX A: LETTER OF INFORMED CONSENT

UNIVERSITEIT VAN PRETORIA
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UNIVERSITEIT VAN PRETORIA
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Faculty of Humanities
Department of Communication Pathology

5 February 2010

Dear Participant,

REQUEST FOR YOUR VOLUNTARY PARTICIPATION IN A RESEARCH PROJECT

I am registered for the degree D.Phil in Communication Pathology in the Dept of Communication Pathology at the University of Pretoria. As part of the requirements for my degree I am conducting research with the aim of determining the influence of non-linear frequency compression on music perception.

There are many people with a hearing loss whose hearing thresholds at the higher frequencies preclude the perception of any useful amplified sound at these points. In order for them to receive usable information about incoming high frequency sounds, a different approach is needed. One way this can be accomplished is by employing a different concept in hearing amplification, one that processes and delivers high frequency speech sounds to the lower frequencies, where people are likely to have more residual hearing. Various signal processing strategies such as non-linear frequency compression have emerged to allow high frequency information to be moved to a lower frequency region so that it can be more easily accessed by the listener. Although some research about the influence of non-linear frequency compression on speech recognition and speech understanding have already been done, there still is no studies to prove whether non-linear frequency compression is suitable for music listening or not, or how non-linear frequency compression will influence the perception of listening to music. This is probably because traditional approaches by the hearing aid industry focused on hearing speech and not music. The determination of the influence of non-linear frequency compression on music perception will assist in more evidence-based hearing aid fittings to improve these skills for persons with a severe hearing loss.

Your participation in this study will assist in collecting valuable information that will enable audiologists to improve service delivery to this population. It will be much appreciated if you will take part in this research project. During the research project you will undergo a hearing test. Thereafter you will be fitted with the non-linear frequency compression hearing aids and requested to wear the hearing aids for a period of four weeks. On returning to the practice you will participate in a music perception test and you will be asked to complete a short questionnaire. You will then be asked to

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wear the hearing aids for another four weeks, this time with the settings differing from the previous. The same music perception test will be conducted when you return to the practice and you will be asked to complete another short questionnaire. Please take note that by agreeing to participate in this study, your personal records in your file at the practice will be reviewed in order to obtain your biographical information. The estimated time that the test procedures will take is approximately one hour per appointment (three appointments). Please do not leave any question in the questionnaire unanswered.

Participation is entirely voluntary and you can withdraw from the study at any time so you wish. Please note that, to take part in this study, you must be within the ages of 18 years 0 months and 64 years 11 months and have no experience with hearing aids that make use of non-linear frequency compression.

Results of this study will be stored on a CD for 15 years and published in a scientific article as well as in the format of a report (hard copy) in the Academic Information Centre of the University of Pretoria. The data collected will be stored for research purposes. All results will be treated in a strictly confidential manner.

Please complete the agreement below and keep it as a reference for the participation of this study.

Your participation is highly appreciated.

Kind regards,

MUys

Marinda Uys
Student number: 21071871
Researcher

MSoer (namens Pottas)

Dr L. Pottas
Research Co-supervisor

vanDijk

Dr C. van Dijk
Research Supervisor

MSoer

Dr M. Soer
Acting Head: Dept of Communication Pathology

Contact Details:
Email: marinda.uys@gmail.com
Tel No: 072 2110 140

APPENDIX B: ETHICAL CLEARANCE

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Faculty of Humanities
Research Ethics Committee

24 February 2010

Dear Dr van Dijk

Project:	**The influence of non-linear frequency compression on music perception for adults with a moderate to severe hearing loss**
Researcher:	**M Uys**
Supervisor:	**Dr C van Dijk**
Department:	**Communication Pathology**
Reference number:	**21071871**

Thank you for your response to the Committee's letter of 10 February 2010.

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 23 February 2010. Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should your actual research depart significantly from the proposed research (as sometimes happens for a variety of possible reasons), it would be necessary to apply for a new research approval and ethical clearance.

The Committee requests you to convey this approval to Ms Uys.

We wish you success with the project.

Sincerely

Prof. John Sharp
Chair: Research Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: john.sharp@up.ac.za

APPENDIX C: LETTER TO REQUEST PERMISSION FROM THE PRIVATE AUDIOLOGY PRACTICE

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Faculty of Humanities
Department of Communication Pathology

30 May 2009

Dear Mrs A van der Merwe,

PERMISSION TO CONDUCT A RESEARCH PROJECT INVOLVING CLIENTS OF THE A. VAN DER MERWE INC. AUDIOLOGY PRACTICE IN PRETORIA

I am registered for the degree D.Phil in Communication Pathology in the Dept of Communication Pathology at the University of Pretoria. As part of the requirements for my degree I am conducting research with the aim of determining the influence of non-linear frequency compression on music perception.

There are many people with a hearing loss whose hearing thresholds at the higher frequencies preclude the perception of any useful amplified sound at these points. In order for them to receive usable information about incoming high frequency sounds, a different approach is needed. One way this can be accomplished is by employing a different concept in hearing amplification, one that processes and delivers high frequency speech sounds to the lower frequencies, where people are likely to have more residual hearing. Various signal processing strategies such as non-linear frequency compression have emerged to allow high frequency information to be moved to a lower frequency region so that it can be more easily accessed by the listener. Although some research about the influence of non-linear frequency compression on speech recognition and speech understanding have already been done, there still is no studies to prove whether non-linear frequency compression is suitable for music listening or not, or how non-linear frequency compression will influence the perception of listening to music. This is probably because traditional approaches by the hearing aid industry focused on hearing speech and not music. The determination of the influence of non-linear frequency compression on music perception will assist in more evidence-based hearing aid fittings to improve these skills for persons with a moderate to severe hearing loss.

Participants:
Voluntary participation of as many clients with a bilateral, severe, sensory neural hearing loss. Participants must be able to understand English and be between the ages of 18 years 0 months and 64 years 11 months. Furthermore participants should not have had hearing aids that made use of the non-linear frequency compression strategy before.

Procedure:
This study involves the audiological testing of participants to determine their hearing status. Thereafter they will be fitted with hearing aids with the non-linear frequency compression algorithm inactive. After the participants had been wearing the hearing aids

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YUNIBESITHI YA PRETORIA

for a period of four weeks, they will be asked to return to the practice where a self-compiled music perception test will be performed. They will also be asked to complete a short questionnaire. The non-linear frequency compression algorithm will then be activated and the participants will be asked to wear the hearing aids again for four weeks. On returning to the practice the same music perception test will be performed. The results obtained with the non-linear frequency compression algorithm disabled and enabled will be evaluated and compared for each participant. The participants will again be asked to complete a short questionnaire to indicate the benefit (if any) with the non-linear frequency compression algorithm activated. Please take note that patients' personal records in their files will be reviewed in order to obtain their biographical information.

Results of this study will be stored on a CD for 15 years and published in a scientific article as well as in the format of a report (hard copy) in the Academic Information Centre of the University of Pretoria. The data collected will be stored for research purposes. All results will be treated in a strictly confidential manner.

Time when study will be conducted:
The data collection will take place as soon as possible after the necessary permission for the conduction of this study was granted by your institution and ethical clearance have been obtained by the University of Pretoria.

It will be highly appreciated if permission can be obtained to conduct this research project at the A. van der Merwe Inc. Audiology practice in Pretoria and if clients of the practice can be used as participants in the study. I am aware of the ethical implications of such a study and am willing to subdue myself to the rules and regulations of your institution.

I trust that you will favourably consider my application.

Kind regards,

M Uys

Marinda Uys
Student number: 21071871
Researcher

Dr. C van Dijk
Research Supervisor

M Soer (nms L Pottas)

Dr L. Pottas
Research Co-supervisor

Dr M. Soer
Acting Head: Dept of Communication Pathology

Contact Details:
Email: marinda.uys@gmail.com
Tel No: 072 2110 140

APPENDIX D: PERMISSION OBTAINED FROM THE PRIVATE AUDIOLOGY PRACTICE

A van der Merwe Inc.
Group Practice No. 5002508

Ballito (KZN) Tel: (032) 946-3987
Bloemfontein Tel: (051) 444-1596
Bellville (CPT) Tel: (012) 949-2900
Bryanston (JHB) Tel: (011) 463-9051
Claremont (CPT) Tel: (021) 683-5590
George Tel: (044) 884-1956
Hillcrest (KZN) Tel: (031) 765-7501
Middelburg Tel: (013) 282-0773
Nelspruit Tel: (013) 752-6680
Pietermaritzburg (KZN) Tel: (033) 345-1060
Polokwane Tel: (015) 291-5989
Potchefstroom Tel: (018) 290-5579
Pretoria Tel: (012) 333-3155
Rosebank (JHB) Tel: (011) 880-4585
Shelly Beach (KZN) Tel: (039) 315-0893
Umhlanga (KZN) Tel: (031) 566-4727
Witbank Tel: (013) 656-1775

4 June 2009

To whom it may concern:

PERMISSION FOR CONDUCTION OF A RESEARCH PROJECT AT THE A. VAN DER MERWE INC. AUDIOLOGY PRACTICE IN PRETORIA

Hereby the directors of the A. van der Merwe Inc. Audiology practice grant permission for the conduction of the doctoral research study by Marinda Uys at the premises. We also grant permission that Mrs Uys may use the clients of this practice as participants in the study.

It will be appreciated if the results of this research project will be shared with the directors and audiologists at the practice.

Please feel free to contact me if you require any further assistance or would like to make arrangements for the conduction of the research project.

Kind regards

A v d. Merwe.

ANITA VAN DER MERWE

DIRECTOR

APPENDIX E: FINAL VERSION OF THE MUSIC PERCEPTION TEST

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

MUSIC PERCEPTION EVALUATION

ANSWER SHEET

NAME: .... DATE OF BIRTH: | D | D | M | M | Y | Y | Y | Y |

DATE: .... (MM/DD/YYYY)

Welcome to the Music Perception Test. Over the course of the next hour, you will be required to respond to various questions relating to music perception.

The test is divided into four sections - A, B, C and D - and each section focuses on a a different aspect of music perception. These aspects are: Rhythm, Timbre, Pitch and Melody.

Please make sure that you are comfortable and remember to put your name, today's date as well as your date of birth on this answer sheet. Also remember that once a question is completed, you cannot return to it.

Your participation is much appreciated.

Please turn this page over to start with the evaluation.

NOTES:

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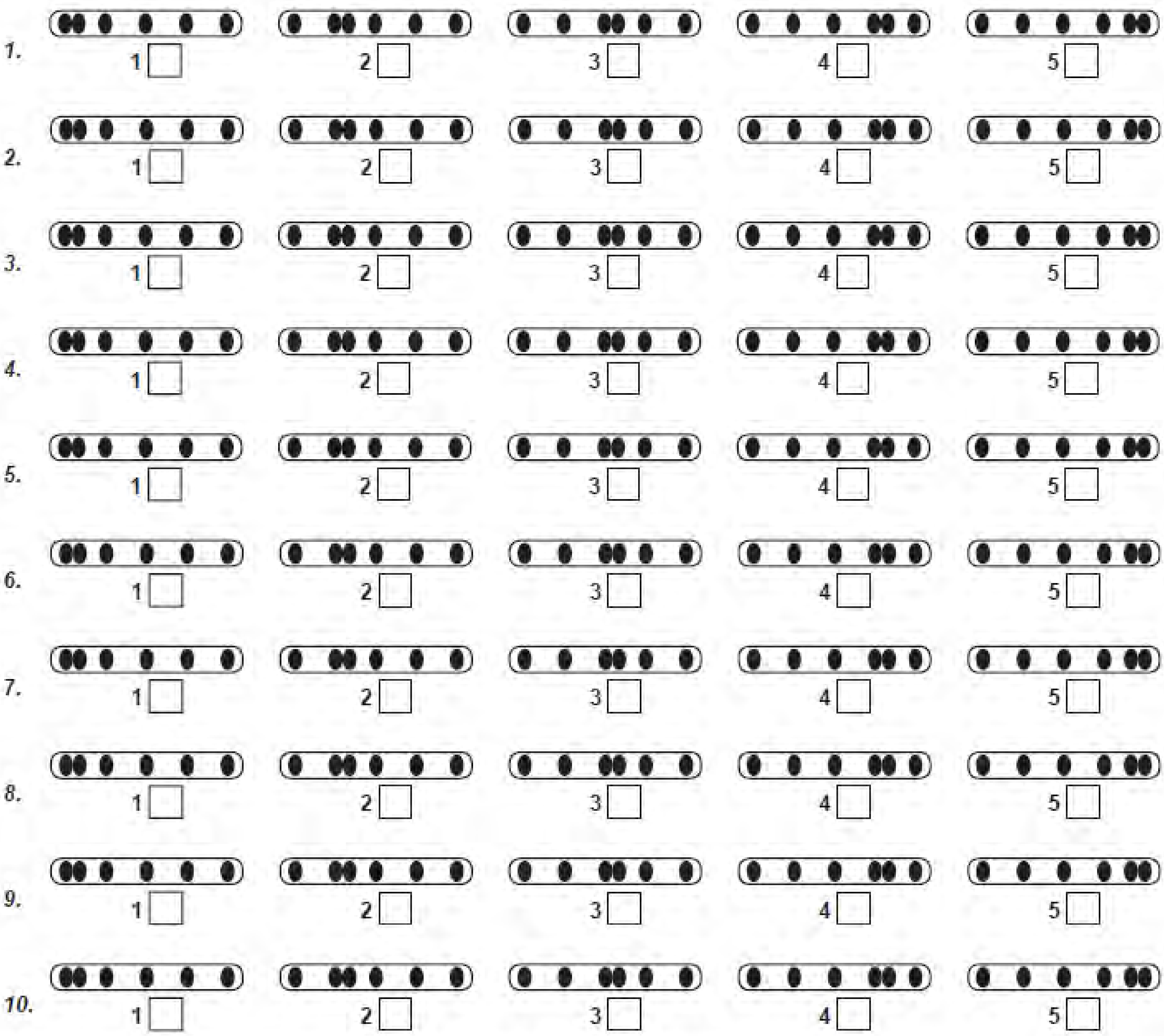
GRAND TOTAL:
140

TEST 1 - RHYTHM IDENTIFICATION

In this test you will be presented with a series of pulse tones, of which two in the series will sound closer together than the rest. (See the graphical representation of this, below). After hearing each series of pulse tones, you must indicate which graphical representation you just heard. There are five in total. Indicate your answer by selecting which one of the five graphical representations you hear.



TOTAL:

TEST 2 - RHYTHM DIS

In this test you will be presented with ten pairs of short melodic patterns. After listening to each pair in turn, you must indicate whether the rhythm of the patterns is the same, or different. Indicate by selecting either 'YES' if they are the same, or 'NO' if they are different.

1. YES ☐ NO ☐	2. YES ☐ NO ☐	3. YES ☐ NO ☐	4. YES ☐ NO ☐	5. YES ☐ NO ☐
6. YES ☐ NO ☐	7. YES ☐ NO ☐	8. YES ☐ NO ☐	9. YES ☐ NO ☐	10. YES ☐ NO ☐

TOTAL: ☐

TEST 3 - RHYTHM RECOGNITION

In this test, you will be presented with ten melodies which are rhythmically structured as either a WALTZ or a MARCH. After listening to each in turn, you must indicate which of the two rhythmical structures you just heard. Indicate your answer by selecting 'WALTZ' or 'MARCH'.

1. WALTZ ☐ MARCH ☐	2. WALTZ ☐ MARCH ☐	3. WALTZ ☐ MARCH ☐	4. WALTZ ☐ MARCH ☐	5. WALTZ ☐ MARCH ☐
6. WALTZ ☐ MARCH ☐	7. WALTZ ☐ MARCH ☐	8. WALTZ ☐ MARCH ☐	9. WALTZ ☐ MARCH ☐	10. WALTZ ☐ MARCH ☐

TOTAL: ☐

TEST 4 - SENSING RHYTHM

In this test, you will be presented with ten pairs of melodic sequences. In each pair, either the FIRST or the SECOND melody may be played out of time and will therefore, not be musically rhythmical. Indicate which melodic sequence is played rhythmically in time by selecting 'FIRST', 'SECOND' or 'BOTH'.

1. FIRST ☐ SECOND ☐ BOTH ☐	2. FIRST ☐ SECOND ☐ BOTH ☐	3. FIRST ☐ SECOND ☐ BOTH ☐	4. FIRST ☐ SECOND ☐ BOTH ☐	5. FIRST ☐ SECOND ☐ BOTH ☐
6. FIRST ☐ SECOND ☐ BOTH ☐	7. FIRST ☐ SECOND ☐ BOTH ☐	8. FIRST ☐ SECOND ☐ BOTH ☐	9. FIRST ☐ SECOND ☐ BOTH ☐	10. FIRST ☐ SECOND ☐ BOTH ☐

TOTAL: ☐

TEST 5 - TIMBRE IDENTIFICATION (Single Instruments)

Before we begin with this test, we'd like to invite you to look at the following section. You will notice graphical representations of eight musical instruments, below. Indicate in the space provided whether you know how each of these eight instruments sounds.

CELLO

☐ YES, I know what this sounds like.

CLARINET

☐ YES, I know what this sounds like.

PIANO

☐ YES, I know what this sounds like.

PICCOLO FLUTE

☐ YES, I know what this sounds like.

SAXOPHONE

☐ YES, I know what this sounds like.

TROMBONE

☐ YES, I know what this sounds like.

TRUMPET

☐ YES, I know what this sounds like.

VIOLIN

☐ YES, I know what this sounds like.

In this test, you will be presented with sixteen musical phrases, played by each of these eight instruments. Indicate which instrument played which phrase by writing the name of the instrument in the space provided.

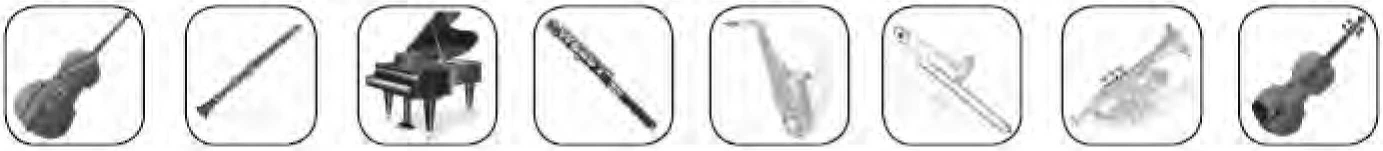
1.	6.	11.
2.	7.	12.
3.	8.	13.
4.	9.	14.
5.	10.	15.
		16.

TOTAL:

TEST 5 - TIMBRE IDEN... (Multiple Instruments)

In this test, you will be presented with the same sixteen musical phrases you heard in the previous test. The phrases, however, will be played as an ensemble - more than one instrument playing at the same time. Indicate which instruments you hear in each collection by writing down their respective names in the space provided.

CELLO CLARINET PIANO PICCOLO FLUTE SAXOPHONE TROMBONE TRUMPET VIOLIN



1.		9.	
2.		10.	
3.		11.	
4.		12.	
5.		13.	
6.		14.	
7.		15.	
8.		16.	

TOTAL:

TEST 6 - THE IDENTIFICATION OF THE NUMBER OF INSTRUMENTS

In this test, you will be presented with five different instruments. A Cello, a Piccolo Flute, a Snare Drum, a Xylophone and a Trumpet. Indicate the number of instruments you can hear playing together by writing the number in the space provided.

1.		*2.*		*3.*		*4.*	
5.		*6.*		*7.*		*8.*	

TOTAL:

SECTION C - PITCH

TEST 7 - PITCH IDENTIFICATION

In this test you will be presented with ten pairs of musical notes. After listening to each pair in turn, you must indicate whether the second note is higher or lower in tone than the first. Indicate by selecting either 'HIGH' or 'LOW'.

1. HIGH ☐ LOW ☐	2. HIGH ☐ LOW ☐	3. HIGH ☐ LOW ☐	4. HIGH ☐ LOW ☐	5. HIGH ☐ LOW ☐
6. HIGH ☐ LOW ☐	7. HIGH ☐ LOW ☐	8. HIGH ☐ LOW ☐	9. HIGH ☐ LOW ☐	10. HIGH ☐ LOW ☐

TOTAL: ☐

TEST 8 - PITCH DISCRIMINATIOIN

In this test you will be presented with ten pairs of short melodic sequences. After listening to each pair in turn, you must indicate whether the melodic sequences are the same, or different. Indicate by selecting 'YES' if they are the same, or 'NO' if they are different.

1. YES ☐ NO ☐	2. YES ☐ NO ☐	3. YES ☐ NO ☐	4. YES ☐ NO ☐	5. YES ☐ NO ☐
6. YES ☐ NO ☐	7. YES ☐ NO ☐	8. YES ☐ NO ☐	9. YES ☐ NO ☐	10. YES ☐ NO ☐

TOTAL: ☐

TEST 9 - MUSICALITY

In this test you will be presented with ten pairs of tonal phrases played on the piano. You must indicate which phrase in each pair you consider to be the more musical or pleasant to listen to - as determined by a structured sequence of notes. Please bear in mind that some phrases in a pair may BOTH be musical or unmusical. Indicate which of the tonal phrases in each pair you think are more musical by selecting the appropriate answer.

1.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

2.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

3.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

4.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

5.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

6.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

7.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

8.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

9.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

10.
- **FIRST** WAS MUSICAL ☐
- **SECOND** WAS MUSICAL ☐
- **BOTH** WERE MUSICAL ☐
- **NONE** WERE MUSICAL ☐

TOTAL: ☐

TEST 10 - MELODY IDI

Please look at the following section. You will see an alphabetical list of ten well-known melodies. Please go through the list and indicate next to the title of each melody whether you are familiar with it. If you are not, just leave the applicable space blank.

1. ☐ '7de Laan' Theme
2. ☐ Happy Birthday To You
3. ☐ Jingle Bells
4. ☐ Mary Had A Little Lamb
5. ☐ Nkosi Sikelel' iAfrika
6. ☐ Nokia Ring Tone
7. ☐ Old MacDonald Had A Farm
8. ☐ Twinkle, Twinkle Little Star
9. ☐ Wedding March
10. ☐ We Wish You A Merry Christmas

In this test, you will be presented with various melodies from the list above. You must indicate the name of the melody that is playing when you hear it by writing down the corresponding number. Bear in mind that any particular melody may be played more than once and it's rhythmical structure may be changed. If you need more time to consider your choice, please indicate this to your examiner by raising your hand.

1. Melody Number	☐	11. Melody Number	☐
2. Melody Number	☐	12. Melody Number	☐
3. Melody Number	☐	13. Melody Number	☐
4. Melody Number	☐	14. Melody Number	☐
5. Melody Number	☐	15. Melody Number	☐
6. Melody Number	☐	16. Melody Number	☐
7. Melody Number	☐	17. Melody Number	☐
8. Melody Number	☐	18. Melody Number	☐
9. Melody Number	☐	19. Melody Number	☐
10. Melody Number	☐	20. Melody Number	☐

TOTAL: ☐

TEST 11 - MUSIC IN N… NTIFICATION

Please look at the section below. You will see an alphabetical list of twenty well-known songs of which all have been used in the popular films listed. Go through the list and indicate next to the title of each song or film whether you are familiar with it. If you are not, just leave the applicable space blank.

1. ☐ **A Whole New World** *from "Aladdin"*
2. ☐ **Beauty And The Beast** *from "Beauty and the Beast"*
3. ☐ **Chariots Of Fire** *from "Chariots Of Fire"*
4. ☐ **Climb Every Mountain** *from "The Sound of Music"*
5. ☐ **Don't Cry For Me Argentina** *from "Evita"*
6. ☐ **Hungry Eyes** *from "Dirty Dancing"*
7. ☐ **I Finally Found Someone** *from "The Mirror Has Two Faces"*
8. ☐ **I Say A Little Prayer For You** *from "My Best Friend's Wedding"*
9. ☐ **I've Had The Time Of My Life** *from "Dirty Dancing"*
10. ☐ **Diamonds Are Forever** *from "Diamonds Are Forever"*
11. ☐ **Leaving On A Jet Plane** *from "Armageddon"*
12. ☐ **Lara's Theme** *from "Doctor Zhivago"*
13. ☐ **My Heart Will Go On** *from "Titanic"*
14. ☐ **The Pink Panther Theme** *from "The Pink Panther"*
15. ☐ **Purple Rain** *from "Purple Rain"*
16. ☐ **Singing In The Rain** *from "Singing In The Rain"*
17. ☐ **Stayin' Alive** *from "Saturday Night Fever"*
18. ☐ **Summer Nights** *from "Grease"*
19. ☐ **Take My Breath Away** *from "Top Gun"*
20. ☐ **Unchained Melody** *from "Ghost"*

In this test, you will be presented with a portion of various songs from the list that will be played in a simulated noisy environment - that of a motor car driving in traffic. Please indicate which song you hear playing, or the movie it's from, by writing down the corresponding number in the space provided.

1. Melody Number	☐	6. Melody Number	☐
2. Melody Number	☐	7. Melody Number	☐
3. Melody Number	☐	8. Melody Number	☐
4. Melody Number	☐	9. Melody Number	☐
5. Melody Number	☐	10. Melody Number	☐

TOTAL: ☐

This concludes our Music Perception Evaluation. Thank you for your participation.

APPENDIX F: MARKING SHEET FOR THE FINAL VERSION OF THE MUSIC PERCEPTION TEST

MUSIC PERCEPTION EVALUATION

ANSWER SHEET

MARKING SHEET

NAME: .... DATE OF BIRTH: D D M M Y Y Y Y

DATE: .... (MM/DD/YYYY)

Welcome to the Music Perception Test. Over the course of the next hour, you will be required to respond to various questions relating to music perception.

The test is divided into four sections - A, B, C and D - and each section focuses on a a different aspect of music perception. These aspects are: Rhythm, Timbre, Pitch and Melody.

Please make sure that you are comfortable and remember to put your name, today's date as well as your date of birth on this answer sheet. Also remember that once a question is completed, you cannot return to it.

Your participation is much appreciated.

Please turn this page over to start with the evaluation.

NOTES:

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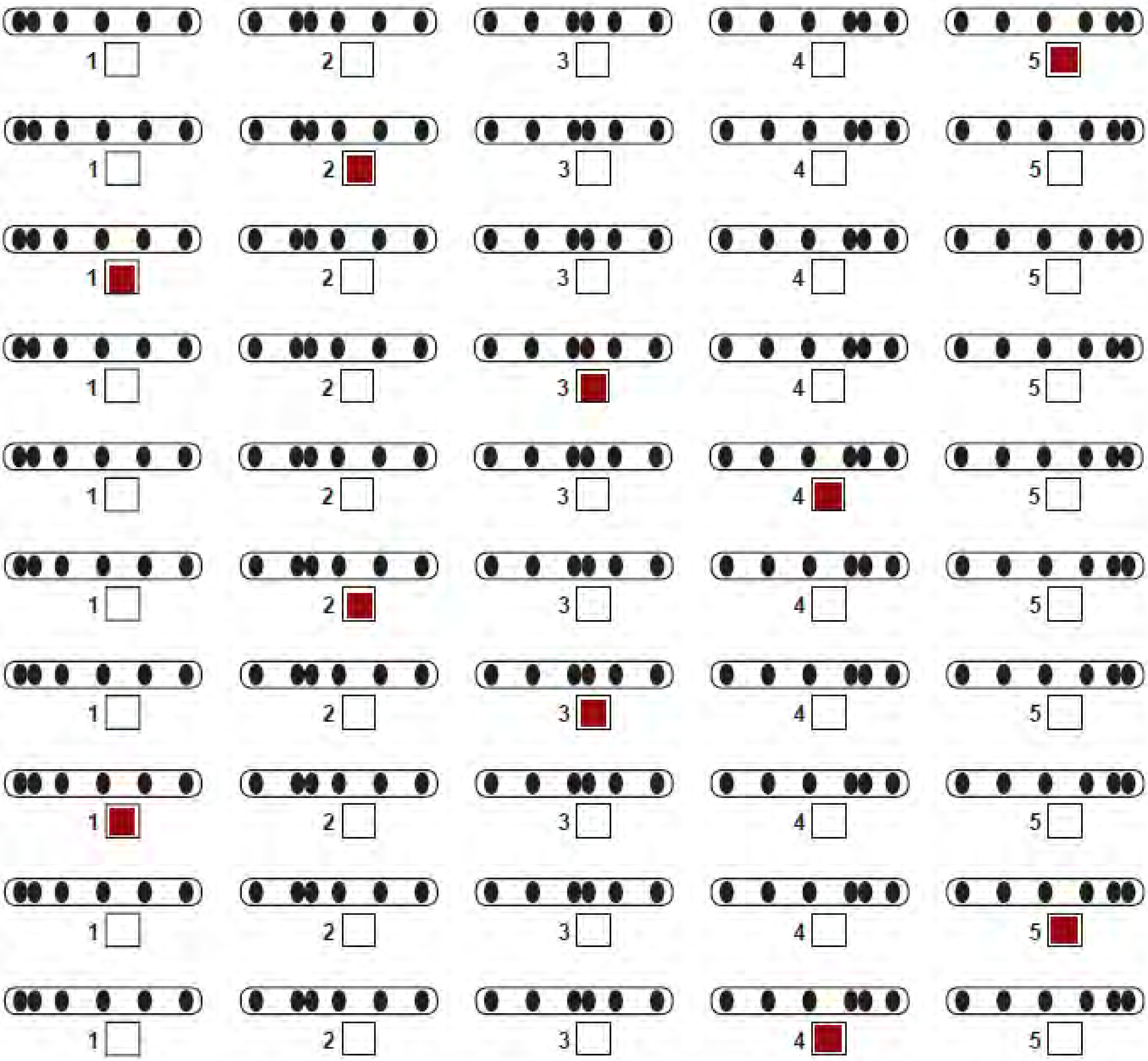
GRAND TOTAL:
140

TEST 1 - RHYTHM IDENTIFICATION

In this test you will be presented with a series of pulse tones, of which two in the series will sound closer together than the rest. (See the graphical representation of this, below). After hearing each series of pulse tones, you must indicate which graphical representation you just heard. There are five in total. Indicate your answer by selecting which one of the five graphical representations you hear.



	1	2	3	4	5
1.	☐	☐	☐	☐	■
2.	☐	■	☐	☐	☐
3.	■	☐	☐	☐	☐
4.	☐	☐	■	☐	☐
5.	☐	☐	☐	■	☐
6.	☐	■	☐	☐	☐
7.	☐	☐	■	☐	☐
8.	■	☐	☐	☐	☐
9.	☐	☐	☐	☐	■
10.	☐	☐	☐	■	☐

TOTAL:

TEST 2 - RHYTHM DIS

In this test you will be presented with ten pairs of short melodic patterns. After listening to each pair in turn, you must indicate whether the rhythm of the patterns is the same, or different. Indicate by selecting either 'YES' if they are the same, or 'NO' if they are different.

	1.	2.	3.	4.	5.
YES	■	□	■	■	□
NO	□	■	□	□	■

	6.	7.	8.	9.	10.
YES	□	□	■	□	■
NO	■	■	□	■	□

TOTAL: ____

TEST 3 - RHYTHM RECOGNITION

In this test, you will be presented with ten melodies which are rhythmically structured as either a WALTZ or a MARCH. After listening to each in turn, you must indicate which of the two rhythmical structures you just heard. Indicate your answer by selecting 'WALTZ' or 'MARCH'.

	1.	2.	3.	4.	5.
WALTZ	■	■	□	□	□
MARCH	□	□	■	■	■

	6.	7.	8.	9.	10.
WALTZ	■	■	□	■	□
MARCH	□	□	■	□	■

TOTAL: ____

TEST 4 - SENSING RHYTHM

In this test, you will be presented with ten pairs of melodic sequences. In each pair, either the FIRST or the SECOND melody may be played out of time and will therefore, not be musically rhythmical. Indicate which melodic sequence is played rhythmically in time by selecting 'FIRST', 'SECOND' or 'BOTH'.

	1.	2.	3.	4.	5.
FIRST	■	■	□	□	□
SECOND	□	□	■	□	■
BOTH	□	□	□	■	□

	6.	7.	8.	9.	10.
FIRST	■	□	■	□	□
SECOND	□	□	□	□	■
BOTH	□	■	□	■	□

TOTAL: ____

TEST 5 - TIMBRE IDENTIFICATION (Single Instruments)

Before we begin with this test, we'd like to invite you to look at the following section. You will notice graphical representations of eight musical instruments, below. Indicate in the space provided whether you know how each of these eight instruments sounds.

CELLO

YES, I know what this sounds like.

CLARINET

YES, I know what this sounds like.

PIANO

YES, I know what this sounds like.

PICCOLO FLUTE

YES, I know what this sounds like.

SAXOPHONE

YES, I know what this sounds like.

TROMBONE

YES, I know what this sounds like.

TRUMPET

YES, I know what this sounds like.

VIOLIN

YES, I know what this sounds like.

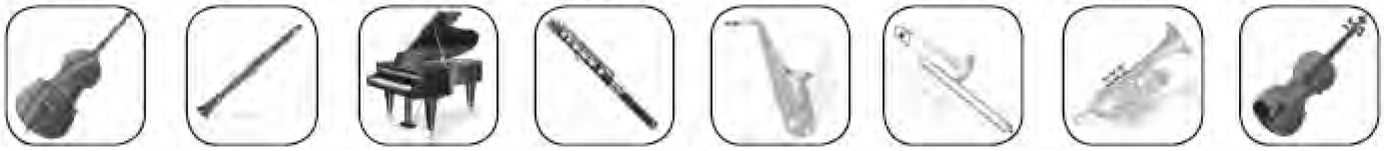
In this test, you will be presented with sixteen musical phrases, played by each of these eight instruments. Indicate which instrument played which phrase by writing the name of the instrument in the space provided.

1. PIANO
2. PICCOLO FLUTE
3. TRUMPET
4. CELLO
5. TROMBONE
6. PIANO
7. CLARINET
8. SAXOPHONE
9. VIOLIN
10. CELLO
11. SAXOPHONE
12. TRUMPET
13. VIOLIN
14. PICCOLO FLUTE
15. TROMBONE
16. CLARINET

TOTAL:

TEST 5 - TIMBRE IDEN Multiple Instruments)

In this test, you will be presented with the same sixteen musical phrases you heard in the previous test. The phrases, however, will be played as an ensemble - more than one instrument playing at the same time. Indicate which instruments you hear in each collection by writing down their respective names in the space provided.



1.	PICCOLO FLUTE/SAXOPHONE	9.	SAXOPHONE/VIOIN
2.	CLARINET/PIANO	10.	PICCOLO FLUTE/PIANO
3.	SAXOPHONE/VIOIN	11.	CELLO/PIANO/TROMBONE
4.	CELLO/CLARINET	12.	CLARINET/PIANO/TROMBONE
5.	CELLO/PIANO/VIOLIN	13.	CLARINET/PICCOLO FLUTE
6.	CLARINET/PICCOLO FLUTE	14.	PIANO/SAXOPHONE/TRUMPET
7.	CELLO/PIANO/TROMBONE	15.	CELLO/PIANO
8.	PIANO/TRUMPET	16.	CELLO/TRUMPET

TOTAL:

TEST 6 - THE IDENTIFICATION OF THE NUMBER OF INSTRUMENTS

In this test, you will be presented with five different instruments. A Cello, a Piccolo Flute, a Snare Drum, a Xylophone and a Trumpet. Indicate the number of instruments you can hear playing together by writing the number in the space provided.

1.	4	2.	3	3.	4	4.	2
5.	3	6.	5	7.	3	8.	2

TOTAL:

SECTION C - PITCH

TEST 7 - PITCH IDENTIFICATION

In this test you will be presented with ten pairs of musical notes. After listening to each pair in turn, you must indicate whether the second note is higher or lower in tone than the first. Indicate by selecting either 'HIGH' or 'LOW'.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
HIGH	■	☐	■	■	☐	☐	■	☐	■	☐
LOW	☐	■	☐	☐	■	■	☐	■	☐	■

TOTAL:

TEST 8 - PITCH DISCRIMINATIOIN

In this test you will be presented with ten pairs of short melodic sequences. After listening to each pair in turn, you must indicate whether the melodic sequences are the same, or different. Indicate by selecting 'YES' if they are the same, or 'NO' if they are different.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
YES	■	☐	☐	■	☐	☐	☐	■	■	■
NO	☐	■	■	☐	■	■	■	☐	☐	☐

TOTAL:

TEST 9 - MUSICALITY

In this test you will be presented with ten pairs of tonal phrases played on the piano. You must indicate which phrase in each pair you consider to be the more musical or pleasant to listen to - as determined by a structured sequence of notes. Please bear in mind that some phrases in a pair may BOTH be musical or unmusical. Indicate which of the tonal phrases in each pair you think are more musical by selecting the appropriate answer.

1. FIRST was musical ■ / SECOND was musical ☐ / BOTH were musical ☐ / NONE were musical ☐
2. FIRST was musical ☐ / SECOND was musical ■ / BOTH were musical ☐ / NONE were musical ☐
3. FIRST was musical ☐ / SECOND was musical ☐ / BOTH were musical ■ / NONE were musical ☐
4. FIRST was musical ☐ / SECOND was musical ■ / BOTH were musical ☐ / NONE were musical ☐
5. FIRST was musical ■ / SECOND was musical ☐ / BOTH were musical ☐ / NONE were musical ☐
6. FIRST was musical ☐ / SECOND was musical ☐ / BOTH were musical ☐ / NONE were musical ■
7. FIRST was musical ■ / SECOND was musical ☐ / BOTH were musical ☐ / NONE were musical ☐
8. FIRST was musical ☐ / SECOND was musical ☐ / BOTH were musical ■ / NONE were musical ☐
9. FIRST was musical ☐ / SECOND was musical ■ / BOTH were musical ☐ / NONE were musical ☐
10. FIRST was musical ☐ / SECOND was musical ☐ / BOTH were musical ☐ / NONE were musical ■

TOTAL: ☐

TEST 10 - MELODY IDI

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Please look at the following section. You will see an alphabetical list of ten well-known melodies. Please go through the list and indicate next to the title of each melody whether you are familiar with it. If you are not, just leave the applicable space blank.

1. ■ '7de Laan' Theme
2. ■ Happy Birthday To You
3. ■ Jingle Bells
4. ■ Mary Had A Little Lamb
5. ■ Nkosi Sikelel' iAfrika
6. ■ Nokia Ring Tone
7. ■ Old MacDonald Had A Farm
8. ■ Twinkle, Twinkle Little Star
9. ■ Wedding March
10. ■ We Wish You A Merry Christmas

In this test, you will be presented with various melodies from the list above. You must indicate the name of the melody that is playing when you hear it by writing down the corresponding number. Bear in mind that any particular melody may be played more than once and it's rhythmical structure may be changed. If you need more time to consider your choice, please indicate this to your examiner by raising your hand.

1.	Melody Number	2	11.	Melody Number	7
2.	Melody Number	5	12.	Melody Number	6
3.	Melody Number	7	13.	Melody Number	9
4.	Melody Number	9	14.	Melody Number	4
5.	Melody Number	8	15.	Melody Number	5
6.	Melody Number	4	16.	Melody Number	8
7.	Melody Number	1	17.	Melody Number	10
8.	Melody Number	3	18.	Melody Number	3
9.	Melody Number	6	19.	Melody Number	2
10.	Melody Number	10	20.	Melody Number	1

TOTAL:

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TEST 11 - MUSIC IN NO[...]NTIFICATION

Please look at the section below. You will see an alphabetical list of twenty well-known songs of which all have been used in the popular films listed. Go through the list and indicate next to the title of each song or film whether you are familiar with it. If you are not, just leave the applicable space blank.

1. **A Whole New World** from "Aladdin"
2. **Beauty And The Beast** from "Beauty and the Beast"
3. **Chariots Of Fire** from "Chariots Of Fire"
4. **Climb Every Mountain** from "The Sound of Music"
5. **Don't Cry For Me Argentina** from "Evita"
6. **Hungry Eyes** from "Dirty Dancing"
7. **I Finally Found Someone** from "The Mirror Has Two Faces"
8. **I Say A Little Prayer For You** from "My Best Friend's Wedding"
9. **I've Had The Time Of My Life** from "Dirty Dancing"
10. **Diamonds Are Forever** from "Diamonds Are Forever"
11. **Leaving On A Jet Plane** from "Armageddon"
12. **Lara's Theme** from "Doctor Zhivago"
13. **My Heart Will Go On** from "Titanic"
14. **The Pink Panther Theme** from "The Pink Panther"
15. **Purple Rain** from "Purple Rain"
16. **Singing In The Rain** from "Singing In The Rain"
17. **Stayin' Alive** from "Saturday Night Fever"
18. **Summer Nights** from "Grease"
19. **Take My Breath Away** from "Top Gun"
20. **Unchained Melody** from "Ghost"

In this test, you will be presented with a portion of various songs from the list that will be played in a simulated noisy environment - that of a motor car driving in traffic. Please indicate which song you hear playing, or the movie it's from, by writing down the corresponding number in the space provided.

1.	Melody Number	15
2.	Melody Number	5
3.	Melody Number	17
4.	Melody Number	9
5.	Melody Number	13
6.	Melody Number	16
7.	Melody Number	20
8.	Melody Number	2
9.	Melody Number	11
10.	Melody Number	3

TOTAL:

This concludes our Music Perception Evaluation. Thank you for your participation.

APPENDIX G: FIRST VERSION OF THE MUSIC PERCEPTION TEST

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MUSIC PERCEPTION EVALUATION

ANSWER SHEET

NAME:	DATE OF BIRTH: D D M M Y Y Y Y

DATE: .... (MM/DD/YYYY)

Welcome to the Music Perception Test. Over the course of the next hour, you will be required to respond to various questions relating to music perception.

The test is divided into four sections - A, B, C and D - and each section focuses on a a different aspect of music perception. These aspects are: Rhythm, Timbre, Pitch and Melody.

Please make sure that you are comfortable and remember to put your name, today's date as well as your date of birth on this answer sheet.

Your participation is much appreciated.

Please turn this page over to start with the evaluation.

NOTES:

....

....

....

....

....

....

....

....

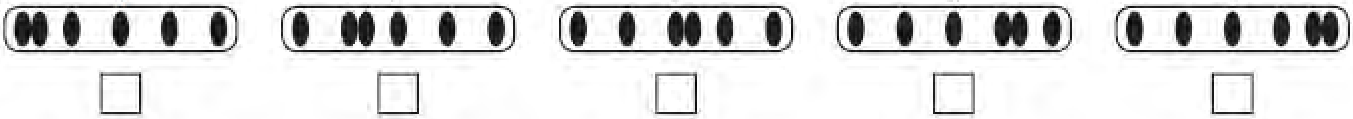
....

GRAND TOTAL: [ ]

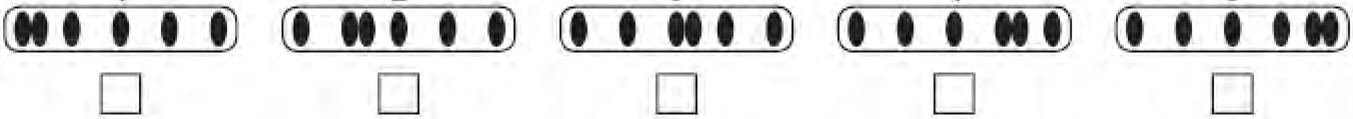
TEST 1 - RHYTHM IDENTIFICATION

In this test you will be presented with a series of pulse tones, of which two in the series will sound closer together than the rest. (See the graphical representation of this, below) After hearing each series of pulse tones, you must indicate which graphical representation you just heard. There are five in total. Indicate your answer by selecting which one of the five graphical representations you hear.

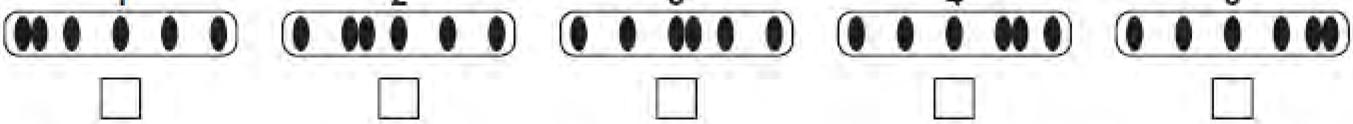
1. 1 2 3 4 5



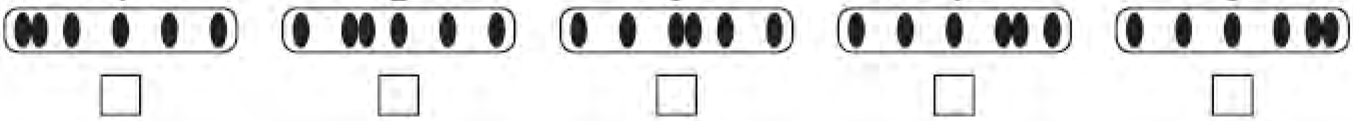
2. 1 2 3 4 5



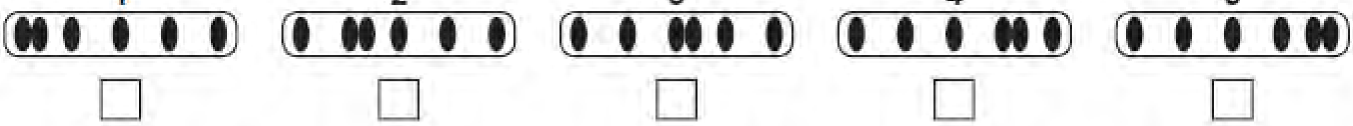
3. 1 2 3 4 5



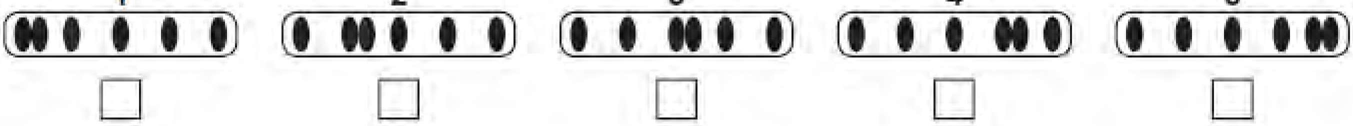
4. 1 2 3 4 5



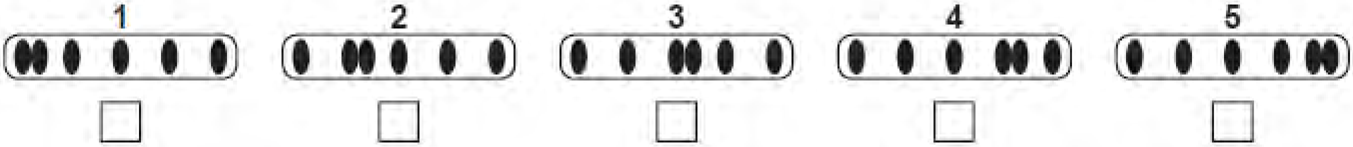
5. 1 2 3 4 5



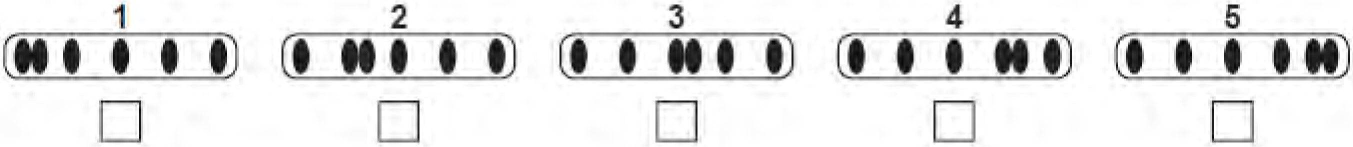
6. 1 2 3 4 5



7. 1 2 3 4 5



8. 1 2 3 4 5



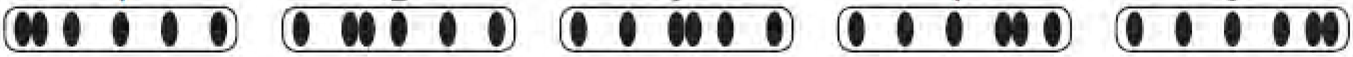
9. 1 2 3 4 5

☐ ☐ ☐ ☐ ☐

10. 1 2 3 4 5

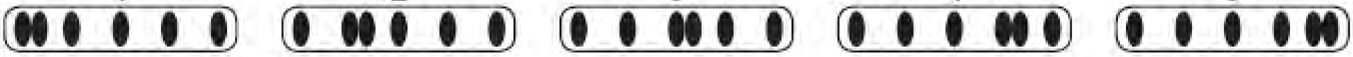
☐ ☐ ☐ ☐ ☐

11. 1 2 3 4 5



☐ ☐ ☐ ☐ ☐

12. 1 2 3 4 5



☐ ☐ ☐ ☐ ☐

TOTAL: ☐

TEST 2 - RHYTHM DISCRIMINATION

In this test you will be presented with twelve pairs of short melodic patterns. After listening to each pair in turn, you must indicate whether the rhythm of the patterns are the same, or different. Indicate by selecting either 'YES' if they are the same, or 'NO' if they are different.

1. **YES** ☐ **NO** ☐	2. **YES** ☐ **NO** ☐	3. **YES** ☐ **NO** ☐	4. **YES** ☐ **NO** ☐
5. **YES** ☐ **NO** ☐	6. **YES** ☐ **NO** ☐	7. **YES** ☐ **NO** ☐	8. **YES** ☐ **NO** ☐
9. **YES** ☐ **NO** ☐	10. **YES** ☐ **NO** ☐	11. **YES** ☐ **NO** ☐	12. **YES** ☐ **NO** ☐

TOTAL: ☐

TEST 3 - RHYTHM REC

In this test, you will be presented with twelve melodies which are rhythmically structured as either a WALTZ or a MARCH. After listening to each in turn, you must indicate which of the two rhythmical structures you just heard. Indicate your answer by selecting 'WALTZ' or 'MARCH'.

1. **WALTZ** ☐ **MARCH** ☐	2. **WALTZ** ☐ **MARCH** ☐	3. **WALTZ** ☐ **MARCH** ☐	4. **WALTZ** ☐ **MARCH** ☐
5. **WALTZ** ☐ **MARCH** ☐	6. **WALTZ** ☐ **MARCH** ☐	7. **WALTZ** ☐ **MARCH** ☐	8. **WALTZ** ☐ **MARCH** ☐
9. **WALTZ** ☐ **MARCH** ☐	10. **WALTZ** ☐ **MARCH** ☐	11. **WALTZ** ☐ **MARCH** ☐	12. **WALTZ** ☐ **MARCH** ☐

TOTAL: ☐

TEST 4 - RHYTHM PERCEPTION

In this test, you will be presented with twelve pairs of melodic sequences. In each pair, either the FIRST or the SECOND melody may be played out of time and will therefore, not be musically rhythmical. Indicate which melodic sequence is played rhythmically in time by selecting 'FIRST', 'SECOND' or 'BOTH'.

1. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	2. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	3. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	4. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐
5. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	6. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	7. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	8. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐
9. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	10. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	11. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐	12. **FIRST** ☐ **SECOND** ☐ **BOTH** ☐

TOTAL: ☐

TEST 5 - TIMBRE IDENTIFICATION PART ONE

Before we begin with this test, we'd like to invite you to look at the following section. You will notice graphical representations of eight musical instruments, below. Indicate in the space provided whether you know how each of these eight instruments sounds.

CELLO

☐ YES, I know what this sounds like.

CLARINET

☐ YES, I know what this sounds like.

PIANO

☐ YES, I know what this sounds like.

PICCOLO FLUTE

☐ YES, I know what this sounds like.

SAXOPHONE

☐ YES, I know what this sounds like.

TROMBONE

☐ YES, I know what this sounds like.

TRUMPET

☐ YES, I know what this sounds like.

VIOLIN

☐ YES, I know what this sounds like.

In this test, you will be presented with sixteen musical phrases, played by each of these eight instruments. Indicate which instrument played which phrase by writing the name of the instrument in the space provided.

1.		6.		11.	
2.		7.		12.	
3.		8.		13.	
4.		9.		14.	
5.		10.		15.	
				16.	

TOTAL:

TEST 5 - TIMBRE IDEN ART TWO

In this test, you will be presented with the same sixteen musical phrases you heard in Part ONE. The phrases, however, will be played as an ensemble - more than one instrument playing at the same time. Indicate which instruments you hear in each ensemble by writing down their respective names in the space provided.

1.		9.	
2.		10.	
3.		11.	
4.		12.	
5.		13.	
6.		14.	
7.		15.	
8.		16.	

TOTAL:

TEST 6 - NUMBER OF INSTRUMENTS

In this test, you will be presented with five different instruments. A Cello, a Piccolo Flute, a Snare Drum, a Xylophone and a Trumpet. Indicate the number of instruments you can hear playing together by writing the number in the space provided.

1.		2.		3.		4.	
5.		6.		7.		8.	

TOTAL:

TEST 7 - PITCH IDENTIFICATION

In this test you will be presented with twelve pairs of musical notes. After listening to each pair in turn, you must indicate whether the second note is higher or lower in tone than the first. Indicate by selecting either 'HIGH' or 'LOW'.

1. **HIGH** ☐ **LOW** ☐
2. **HIGH** ☐ **LOW** ☐
3. **HIGH** ☐ **LOW** ☐
4. **HIGH** ☐ **LOW** ☐
5. **HIGH** ☐ **LOW** ☐
6. **HIGH** ☐ **LOW** ☐
7. **HIGH** ☐ **LOW** ☐
8. **HIGH** ☐ **LOW** ☐
9. **HIGH** ☐ **LOW** ☐
10. **HIGH** ☐ **LOW** ☐
11. **HIGH** ☐ **LOW** ☐
12. **HIGH** ☐ **LOW** ☐

TOTAL: ☐

TEST 8 - PITCH DISCRIMINATIOIN

In this test you will be presented with twelve pairs of short melodic sequences. After listening to each pair in turn, you must indicate whether the melodic sequences are the same, or different. Indicate by selecting 'YES' if they are the same, or 'NO' if they are different.

1. **YES** ☐ **NO** ☐
2. **YES** ☐ **NO** ☐
3. **YES** ☐ **NO** ☐
4. **YES** ☐ **NO** ☐
5. **YES** ☐ **NO** ☐
6. **YES** ☐ **NO** ☐
7. **YES** ☐ **NO** ☐
8. **YES** ☐ **NO** ☐
9. **YES** ☐ **NO** ☐
10. **YES** ☐ **NO** ☐
11. **YES** ☐ **NO** ☐
12. **YES** ☐ **NO** ☐

TOTAL: ☐

TEST 9 - MUSICALITY PERCEPTION

In this test you will be presented with twelve pairs of tonal phrases played on the piano. You must indicate which phrase in each pair you consider to be the more musical - as determined by a structured sequence of notes. Please bear in mind that some phrases in a pair may BOTH be musical or unmusical. Indicate which of the tonal phrases in each pair you think are more musical by selecting the appropriate answer.

1. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

2. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

3. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

4. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

5. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

6. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

7. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

8. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

9. **FIRST** WAS MUSICAL ☐
   SECOND WAS MUSICAL ☐
   BOTH WERE MUSICAL ☐
   NONE WERE MUSICAL ☐

10. **FIRST** WAS MUSICAL ☐
    SECOND WAS MUSICAL ☐
    BOTH WERE MUSICAL ☐
    NONE WERE MUSICAL ☐

11. **FIRST** WAS MUSICAL ☐
    SECOND WAS MUSICAL ☐
    BOTH WERE MUSICAL ☐
    NONE WERE MUSICAL ☐

12. **FIRST** WAS MUSICAL ☐
    SECOND WAS MUSICAL ☐
    BOTH WERE MUSICAL ☐
    NONE WERE MUSICAL ☐

TOTAL: ☐

TEST 10 - MELODY IDENTIFICATION

Please look at the the following section. You will see an alphabetical list of twelve well-known melodies. Please go through the list and indicate next to the title of each melody whether you are familiar with it. If you are not, just leave the applicable space blank.

1. ☐ '7de Laan' Theme
2. ☐ Baa Baa Black Sheep
3. ☐ For He's A Jolly Good Fellow
4. ☐ Happy Birthday To You
5. ☐ Jingle Bells
6. ☐ Mary Had A Little Lamb
7. ☐ Nokia Ring Tone
8. ☐ Old MacDonald Had A Farm
9. ☐ Nkosi Sikelel' iAfrika
10. ☐ Twinkle, Twinkle Little Star
11. ☐ We Wish You A Merry Christmas
12. ☐ Wedding March

In this test, you will be presented with various melodies from the list above. You must indicate the name of the melody that is playing when you hear it by writing down the corresponding number. Bear in mind that any particular melody may be played more than once and it's rhythmical structure may be changed.

1. Melody Number	☐	13. Melody Number	☐
2. Melody Number	☐	14. Melody Number	☐
3. Melody Number	☐	15. Melody Number	☐
4. Melody Number	☐	16. Melody Number	☐
5. Melody Number	☐	17. Melody Number	☐
6. Melody Number	☐	18. Melody Number	☐
7. Melody Number	☐	19. Melody Number	☐
8. Melody Number	☐	20. Melody Number	☐
9. Melody Number	☐	21. Melody Number	☐
10. Melody Number	☐	22. Melody Number	☐
11. Melody Number	☐	23. Melody Number	☐
12. Melody Number	☐	24. Melody Number	☐

TOTAL: ☐

TEST 11 - MUSIC IN N NTIFICATION

Please look at the section below. You will see an alphabetical list of twenty well-known songs or melodies, all of which have been used in popular films. Go through the list and indicate next to the title of each melody or song whether you are familiar with it. If you are not, just leave the applicable space blank.

1. ☐ A Whole New World
2. ☐ Beauty And The Beast
3. ☐ Chariots Of Fire
4. ☐ Climb Every Mountain
5. ☐ Don't Cry For Me Argentina
6. ☐ Hungry Eyes
7. ☐ I Finally Found Someone
8. ☐ I Say A Little Prayer For You
9. ☐ I've Had The Time Of My Life
10. ☐ Diamonds Are Forever
11. ☐ Leaving On A Jet Plane
12. ☐ Lara's Theme
13. ☐ My Heart Will Go On
14. ☐ The Pink Panther Theme
15. ☐ Purple Rain
16. ☐ Singing In The Rain
17. ☐ Stayin' Alive
18. ☐ Summer Nights
19. ☐ Take My Breath Away
20. ☐ Unchained Melody

In this test, you will be presented with a portion of various songs from the list that will be played in a simulated noisy environment - that of a motor car driving in traffic. Please indicate which song or melody you hear playing at any given moment by writing down the corresponding number in the space provided.

1. Melody Number ☐
2. Melody Number ☐
3. Melody Number ☐
4. Melody Number ☐
5. Melody Number ☐
6. Melody Number ☐
7. Melody Number ☐
8. Melody Number ☐
9. Melody Number ☐
10. Melody Number ☐
11. Melody Number ☐
12. Melody Number ☐

TOTAL: ☐

This concludes our Music Perception Evaluation. Thank you for your participation.

APPENDIX H: MUSIC PERCEPTION TEST MANUAL

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

MUSIC PERCEPTION TEST: USER GUIDE

INDEX **PAGE**

1. BACKGROUND TO THE TEST

Aim: This test was compiled with the purpose of obtaining objective information regarding hearing aid users' perception of music.

Rationale: The ability to enjoy music is often adversely affected by a hearing loss (Glista & McDermott, 2008:2) and the majority of people wearing hearing instruments complain of the reduced sound quality of music heard through their personal amplification devices (Chasin & Russo, 2004:35). This may be due to the fact that most hearing instruments are designed with the focus on hearing speech sounds and not music, which is often problematic as there are several differences between speech and music.

More and more people with hearing problems are expressing an equal need for their hearing instruments to be fitted optimally for listening to music (Chasin, 2004:10). The escalating interest in musical perception accuracy and enjoyment is also reflected in publications of a variety of investigations utilizing different experiments to assess performance on musical tasks (Fujita & Ito, 1999; Gfeller *et al.*, 2005, 2002, 1997 & 1991; Looi *et al.*, 2008; Nimmons *et al.*, 2008). Most of these studies were however done on cochlear implantees and not hearing aid users. To complicate matters there is no standard test of music perception and different musical styles thrive in striking different acoustical environments (Wessel *et al.*, 2007:1). A further limitation to the choice of measures to access musical skills that are currently available is that most music tests are designed to examine the skills of individuals undergoing formal musical training (Don *et al.*, 1999:158). The aforementioned information highlights the need for a clinically relevant measure of musical recognition and performance by hearing aid users in order to improve the quality of life of these people as well as the services delivered to them.

Conclusion: Not only is the technology for music input still in its infancy, but the research and clinical knowledge of what music lovers need to hear is also still in its early stages of understanding (Chasin & Russo, 2004:35) and clearly, more research is required in this area. This test was designed to address the abovementioned and included different aspects of music perception including rhythm, timbre, pitch and melody.

2. REQUIREMENTS AND SETUP

Requirements

The test is available on CD and therefore you need a **CD player** for presentation. The CD player has to be connected to a **two channel clinical audiometer** as it is presented through the audiometer to the participant sitting inside the soundproof room. The soundproof room should therefore be equipped with **speakers** as the test is presented in free field inside the soundproof room.

Furthermore a copy of the Music Perception Test's answer sheet and a pen/pencil should be provided to the participant as all answers are written directly on the answer sheet.

Setup

Ensure before hand that the CD player and speakers are in good working order to avoid any difficulties during the test procedures and to avoid distortion. Connect the CD player to the audiometer with the cords provided from the CD player manufacturers. The chords from the CD player should be connected to the audiometer in the following manner:

- The chord from the CD player with only one fitting should be entered into the audiometer at the opening marked "1761-9621 (5VDC.2A)".
- The other chord from the CD player consists of two fittings (red and white). The red fittings should be entered into the audiometer at the opening marked "A" and the white fitting just next to it, at the opening marked "B".

The participant should be seated inside the soundproof room, facing the speaker at 45 degrees, at a distance of approximately one meter.

3. RUNNING THE TEST

To present the Music Perception Test through the audiometer, the following settings should be selected on the audiometer:

Channel 1	**Channel 2**
Speaker	Speaker
External A	External B
Right	Left
Interrupt on	Interrupt on
75 dB	75 dB

After the above mentioned settings were selected, the test administer should press "play" on the CD player to start the test. No further selections on the CD player are necessary as the different sub-tests continuously follow on to one another.

It is suggested that a presentation level of 75 dB is selected for the presentation of the test and that hearing aid users are permitted to adjust the volume on their hearing aids for maximum comfort.

The participant will have an answer sheet with a set of written instructions for each test section. All instructions are also presented via the speakers before the onset of each test. A written response from the participant is required for each stimulus in the test. Every test includes two practice items which precede the actual test items.

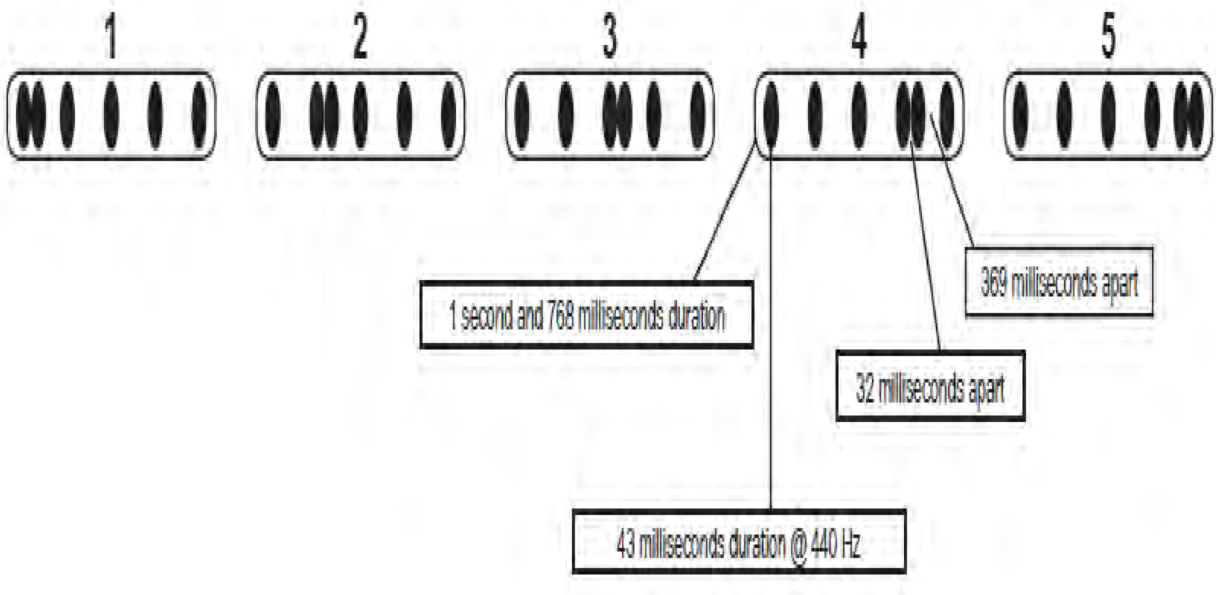
4. THE SPECIFIC SUB-TESTS

<u>Section A - Rhythm</u>

Test 1 – Rhythm identification

In this test the participant is presented with a series of pulse tones, of which two in the series will sound closer together than the rest. After hearing each series of pulse tones, the participant must indicate which graphical representation he/she just heard. There are five in total. The participant indicates his/her answer by selecting which one of the five visual representations on the answer sheet corresponded to the rhythmic pattern they heard. A total of ten items were included in this sub-test.

The following figure is for the visual presentation of the short inter-pulse interval at position four as used in item five:



Test 2 – Rhythm discrimination

In this test the participant will be presented with ten pairs of short melodic patterns. After listening to each pair in turn, the participant must indicate whether the rhythm of the patterns is the same, or different. The participant indicate his/her answer by selecting either "YES" if they are the same, or "NO" if they are different.

The example below is to indicate that the pairs of rhythms are the same, as presented in item one.

YES ■
NO □

Test 3 – Rhythm recognition

In this test, the participant will be presented with ten melodies which are rhythmically structured as either a WALTZ or a MARCH. After listening to each in turn, the participant must indicate which of the two rhythmical structures he/she just heard. The answer is indicated by selecting either "WALTZ" or "MARCH".

The example below is to indicate that the rhythmical structure was that of a march, as presented in item five.

WALTZ □
MARCH ■

Test 4 – Sensing rhythm

In this test, the participant will be presented with ten pairs of melodic sequences. In each pair, either the FIRST or the SECOND melody may be played out of time and will therefore, not be musically rhythmical. The participant should indicate which melodic sequence is played rhythmically in time by selecting "FIRST", "SECOND" or "BOTH".

The example below is to indicate that BOTH melodic sequences were played in time, as presented in item seven.

FIRST □
SECOND □
BOTH ■

Section B - Timbre

Test 5 – Timbre identification (Single instruments)

Participants are asked to indicate which of the musical instruments represented by graphical representations are familiar to them before the onset of the test. They are then presented with sixteen musical phrases, played by each of the eight instruments demonstrated and are asked to indicate which instrument played which phrase by writing the name of the instrument in the space provided.

The example below is to indicate that the participant was familiar with a cello and wrote it's name on the answer sheet as presented in item ten.

Test 5 – Timbre identification (Multiple instruments)

In this test, participants are presented with the same sixteen musical phrases heard in the previous test. The phrases, however, will be played as an ensemble – more than one instrument playing at the same time. The participant is required to indicate which instruments he/she hears in each collection by writing down their respective names in the space provided.

The example below is to indicate that the following three instruments played together during item seven:

CELLO/PIANO/TROMBONE

Test 6 – The identification of the number of instruments

In this test, participants are presented with five different instruments. A Cello, a Piccolo flute, a Snare drum, a Xylophone and a trumpet. They are required to indicate the number of instruments they can hear playing together by writing down the number in the space provided.

The example below is to indicate that four instruments played together as presented in item one:

4

<u>Section C - Pitch</u>

Test 7 – Pitch identification

In this test participants will be presented with ten pairs of musical notes. After listening to each pair in turn, they must indicate whether the second note is higher or lower in tone than the first. The answer is indicated by selecting either "HIGH" or "LOW".

The example below is to indicate that the second note was higher in tone than the first, as presented in item nine:

HIGH ■
LOW □

Test 8 – Pitch discrimination

In this test participants will be presented with ten pairs of short melodic sequences. After listening to each pair in turn, they must indicate whether the melodic sequences are the same, or different. The answer is indicated by selecting "YES" if they are the same, or "NO" if they are different.

The example below is to indicate that the pair of melodic sequences were different, as presented in item six:

YES ☐
NO ■

<u>Section D - Melody</u>

Test 9 – Musicality

In this test participants are presented with ten pairs of tonal phrases played on the piano. They must indicate which phrase in each pair they consider to be the more musical or pleasant to listen to – as determined by a structured sequence of notes. Some phrases in a pair may BOTH be musical or unmusical. The answer to which of the tonal phrases in each pair are more musical is indicated by selecting the appropriate answer on the answer sheet.

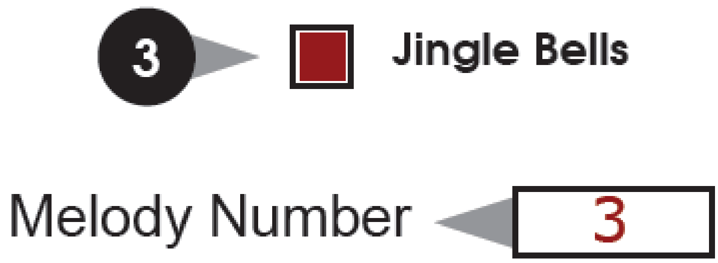
The example below is to indicate that the first musical phrase were musical, as presented in item one:

FIRST WAS MUSICAL ■
SECOND WAS MUSICAL ☐
BOTH WERE MUSICAL ☐
NONE WERE MUSICAL ☐

Test 10 – Melody identification

Participants are presented with an alphabetical list of ten well-known melodies and are asked to indicate next to the title of each melody whether they are familiar with it. If they are not familiar with it, they are instructed to leave the applicable space blank. They are then presented with various melodies from the above-mentioned list and asked to indicate the name of the melody that is playing when they hear it by writing down the corresponding number. Any particular melody can be played more than once and it's rhythmical structure may be changed. If participants need more time to consider their choice, they should indicate this to the examiner by raising a hand.

The example below is to indicate that the participant was familiar with the melody, "Jingle bells", and wrote the corresponding number on the answer sheet as presented in item eight.



Test 11 – Music in noise: Song identification

Participants will see an alphabetical list of twenty well-known songs of which all have been used in popular films. They are required to go through the list and indicate next to the title of each song or film whether they are familiar with it. If they are not familiar with it, they are instructed to leave the applicable space blank. Participants are then presented with a portion of various songs from the list that will be played in a simulated noisy environment – that of a motor car driving in traffic. They should indicate which song they hear playing or the movie it's from, by writing down the corresponding number in the space provided.

The example below is to indicate that the participant was familiar with the song, "Leaving on a jet plane", and wrote the corresponding number on the answer sheet as presented in item nine.

5. CD TRACKS

The test consists of 14 tracks and takes in total 57.17 minutes to complete.

Track 1	Introduction	1.19
Track 2	Test 1: Rhythm identification	2.42
Track 3	Test 2: Rhythm discrimination	4.09
Track 4	Test 3: Rhythm recognition	3.15
Track 5	Test 4: Sensing rhythm	4.24
Track 6	Test 5: Timbre identification (Single instruments)	5.19
Track 7	Test 5: Timbre identification (Multiple instruments)	5.39
Track 8	Test 6: Identification of number of instruments	5.10
Track 9	Test 7: Pitch identification	2.39
Track 10	Test 8: Pitch discrimination	4.00
Track 11	Test 9: Musicality	4.51
Track 12	Test 10: Melody identification	5.58
Track 13	Test 11: Music in noise: Song identification	7.26
Track 14	End	0.19

APPENDIX I: MUSIC PERCEPTION TEST PEER REVIEW EVALUATION SHEET

MUSIC PERCEPTION TEST EVALUATION SHEET

Please read the following questions carefully *and answer them by encircling the applicable answer. Should you wish to add any comments, space has been provided at the end of the evaluation sheet.* ***Please do not leave any question unanswered.***

1. Do you feel that the test appears to measure music perception based on its appearance (in other words, does it look like a music perception test)?

Yes 5 4 3 2 1 No

2. In your opinion, does the test represent a complete assessment of music perception and include the assessment of a whole spectrum of musical skills?

Yes 5 4 3 2 1 No

3. Are you satisfied that the stimuli included in the test, is suitable for the assessment of music perception in hearing aid users?

Yes 5 4 3 2 1 No

4. In your opinion, do the included stimuli have various levels of difficulty and therefore are not too easy or too difficult?

Yes 5 4 3 2 1 No

5. Do you feel that the instructions are clear and precise and therefore enable examinees to understand what is expected of them?

Yes 5 4 3 2 1 No

6. Are you satisfied that the language used in the test is unbiased?

Yes 5 4 3 2 1 No

7. In your opinion, is the test logically organized?

Yes 5 4 3 2 1 No

8. Do you feel that sufficient time is provided to answer questions?

Yes 5 4 3 2 1 No

9. Are you satisfied that the test recording is of a high quality?

Yes 5 4 3 2 1 No

10. Do you feel that the test and test items are appropriate for the South African context and does not consist of culturally biased items, phrases or situations that might be offensive to some individuals?

Yes 5 4 3 2 1 No

Please state any additional comments you may have regarding the test.

____

____

____

____

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APPENDIX J: QUESTIONNAIRE 1

THE INFLUENCE OF NON-LINEAR FREQUENCY COMPRESSION ON MUSIC PERCEPTION

QUESTIONNAIRE 1: BACKGROUND INFORMATION **For office use only**

V1 [ ] [ ] 1
Respondent number

V2 [ ] [ ] 4
[ ] [ ]
[ ] [ ]
Pt Date of birth

Please read the following questions carefully *and answer them by placing a written response in the space provided or tick in the appropriate column/columns. Should you wish to add any comments, space has been provided at the end of the questionnaire.* ***Please do not leave any question unanswered***.

1. For approximately how many years did you receive musical training (instrument and/or voice lessons)?

____ V3 [ ] [ ] 11

2. Please specify the musical instruments that you are currently playing, or have played before:

____ V4 [ ] [ ] 14
____ V5 [ ] [ ] 17

3. Do you currently sing, or have you ever sung, in a choir or on social/professional gatherings?

YES [ ] **NO** [ ] V6 [ ] 20

4. Please specify your highest musical qualification:

____ V7 [ ] [ ] 22

5. Do you consider yourself to be a person with musical talent or musical sense?

YES [ ] **NO** [ ] V8 [ ] 25

6. Do other people consider you to be a person with musical talent or musical sense?

YES [ ] **NO** [ ] V9 [ ] 27

7. Please specify the relationship to you of any persons in your immediate family with an extraordinary musical talent?

____ V10 [ ] [ ] 29
____ V11 [ ] [ ] 32

8. What role does music play in your life? Please circle the applicable answer.

A big role 5 ____ 4 ____ 3 ____ 2 ____ 1 Does not play a role V12 [ ] 35

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9. How often do you listen to music? Please circle the applicable answer.

A lot 5 4 3 2 1 Never V13 ☐ 37

10. How many hours do you usually listen to music on a work day?

____ V14 ☐☐ 39

11. How many hours do you usually listen to music on a day that you are not working (for example over weekends)?

____ V15 ☐☐ 42

12. In which situations do you listen to music? Please tick all the applicable answers.

Over the television	☐	At formal music events	☐	V16	☐☐	45
On the computer	☐	On the radio in the car	☐	V18	☐☐	49
At social events	☐	Hi-Fi/Ipod/MP3	☐	V20	☐☐	53

13. Which musical genre(s) do you listen to?

Classical music	☐	Opera/Operetta	☐	V22	☐☐	57
Pop music	☐	Choir music	☐	V24	☐☐	61
Rock music	☐	Jazz/Blues	☐	V26	☐☐	65
Folk/Country music	☐	Music to dance to	☐	V28	☐☐	69
Ballad singing	☐			V30	☐	73

14. Do you feel that your enjoyment of music has decreased since you started experiencing hearing problems?

YES ☐ **NO** ☐ V31 ☐ 75

15. Do you usually remove your hearing aid when you listen to music?

YES ☐ **NO** ☐ V32 ☐ 77

16. What do you find most annoying when you listen to music with your hearing aid?

____ V33 ☐☐ 79
____ V34 ☐☐ 82

17. Please state any additional comments you may have regarding this subject.

____ V35 ☐☐ 85
____ V36 ☐☐ 88

PLEASE READ THROUGH THE QUESTIONNAIRE TO ENSURE THAT ALL THE QUESTIONS WERE ANSWERED.

THANK YOU FOR YOUR CO-OPERATION

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APPENDIX K: QUESTIONNAIRE 2

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THE INFLUENCE OF NON-LINEAR FREQUENCY COMPRESSION ON MUSIC PERCEPTION

QUESTIONNAIRE 2: IMPRESSION OF MUSIC PERCEPTION **For office use only**

V1			1

Respondent number

V2		4

Compression on/off

***Please read the following questions carefully** and answer them by placing a written response in the space provided or tick in the appropriate column/columns. Should you wish to add any comments, space has been provided at the end of the questionnaire. **Please do not leave any question unanswered**.*

The following questions are regarding your musical experience with the hearing aids as used during the last four weeks.

1. To which musical genre do you listen to mostly (your favorite musical genre)?

Genre		Genre		Office use			
Classical music		Opera/Operetta		V3			6
Pop music		Choir music		V5			10
Rock music		Jazz/Blues		V7			14
Folk/Country music		Music to dance to		V9			18
Ballad singing				V11			22

2. How does listening to your favorite musical genre generally sound with the hearing aid? Please circle the applicable answer.

2.1 **Loudness**: The music is sufficiently loud, as opposed to soft or faint.

Loud 5 — 4 — 3 — 2 — 1 Soft V12 [ ] 24

2.2 **Fullness**: The music is full, as opposed to thin.

Full 5 — 4 — 3 — 2 — 1 Thin V13 [ ] 26

2.3 **Crispness**: The music is clear and distinct, as opposed to blurred and diffuse.

Crisp/ Clear 5 — 4 — 3 — 2 — 1 Blurred V14 [ ] 28

2.4 **Naturalness**: The music seems to be as if there is no hearing aid, and the music seems as "I remember it".

Natural 5 — 4 — 3 — 2 — 1 Unnatural V15 [ ] 30

2.5 **Overall fidelity**: The dynamics and range of the music is not constrained or narrow.

Dynamic 5 — 4 — 3 — 2 — 1 Constrained Narrow V16 [ ] 32

2.6 **Pleasantness**: A feeling of enjoyment or satisfaction, as opposed to annoying or irritating.

Pleasant 5 — 4 — 3 — 2 — 1 Unpleasant V17 [ ] 34

2.7 **Tinniness**: Hearing the quality of tin or metal, a sense of a cheap, low quality sound.

Less tinny 5 — 4 — 3 — 2 — 1 More tinny V18 [ ] 36

2.8 **Reverberant**: The persistence of sound after the original sound is removed, a series of echoes.

Un-reverberant	5	4	3	2	1	Echoeing	V19	38

3. If you listen to music, which elements can you hear? Please tick all the applicable answers.

Pleasant tones, but no melody	☐	Melody	☐	V20	40
Only unpleasant sounds	☐	Lyrics	☐	V22	44
Rhythm	☐			V24	48

4. Can you distinguish between high and low notes?

YES ☐ **NO** ☐ V25 50

5. Can you detect different musical instruments in a musical piece?

YES ☐ **NO** ☐ V26 52

6. Can you discriminate the lyrics (words) in a song?

YES ☐ **NO** ☐ V27 54

7. What did you find most annoying when you listened to music with the hearing aid?

____ V28 56
____ V29 59

8. Please state any additional comments you may have regarding this subject. If you require the results of this study, please indicate it here.

____ V30 62
____ V31 65

9. Do you require the results of this study?

YES ☐ **NO** ☐ V32 68

PLEASE READ THROUGH THE QUESTIONNAIRE TO ENSURE THAT ALL THE QUESTIONS WERE ANSWERED.

THANK YOU FOR YOUR CO-OPERATION