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.

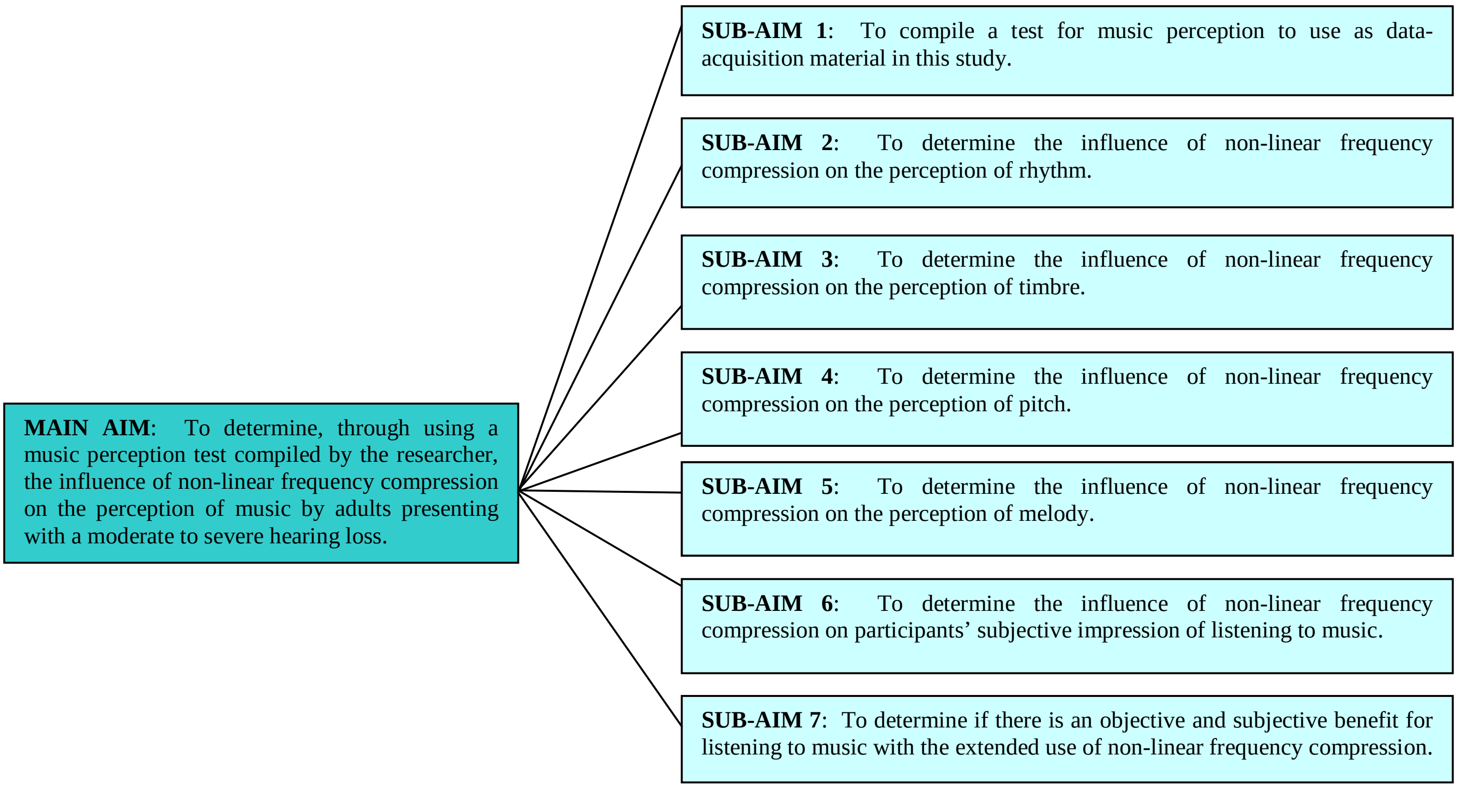

Figure 5-1: Presentation of results in correspondence with the sub-aims

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.

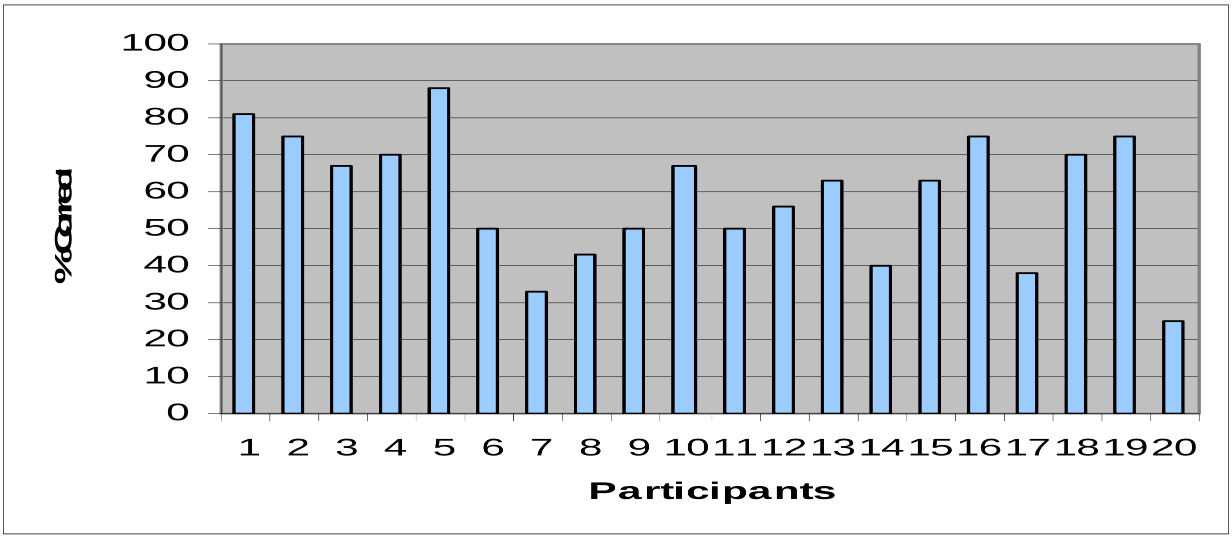

Figure 5-2: Participants' performance on the single instrument identification task (Sub-test 5 part one)

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.

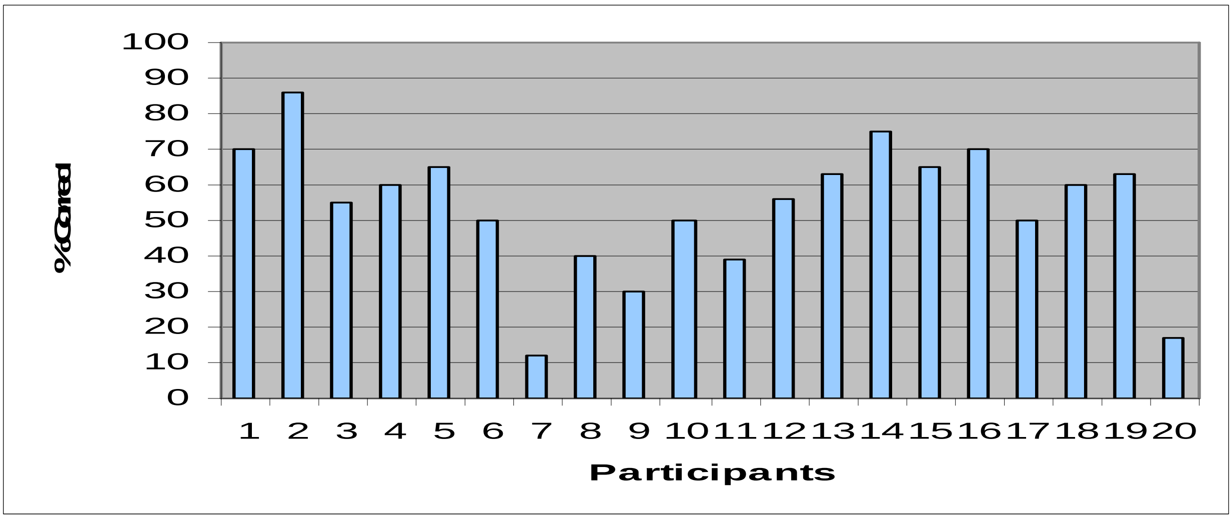

Figure 5-3: Participants' performance on the multiple instrument identification task (Sub-test 5 part two)

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.

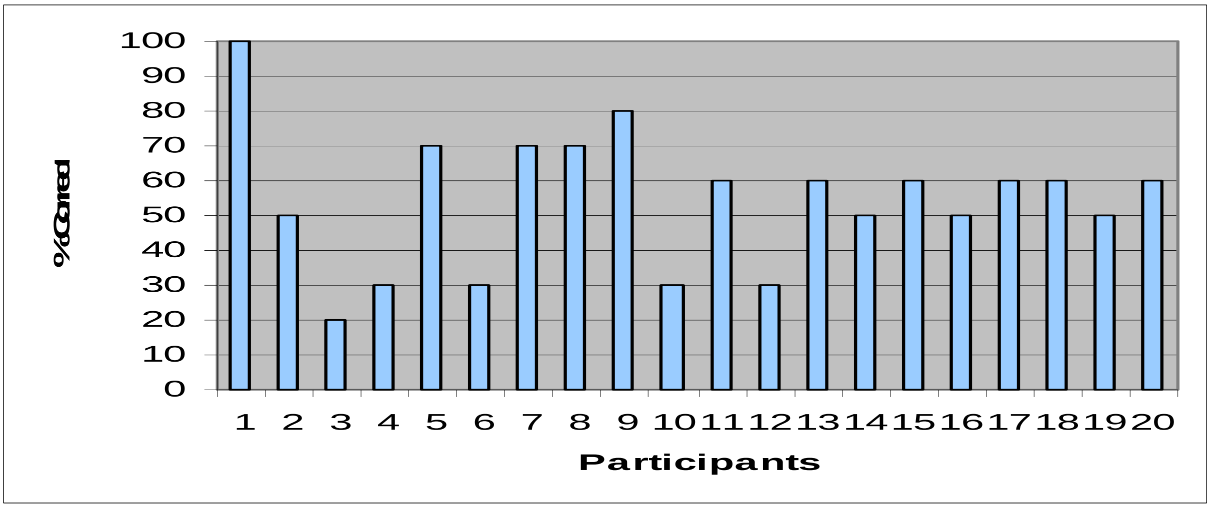

Figure 5-4: Participants' performance on the musicality perception task (Sub-test 9)

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.

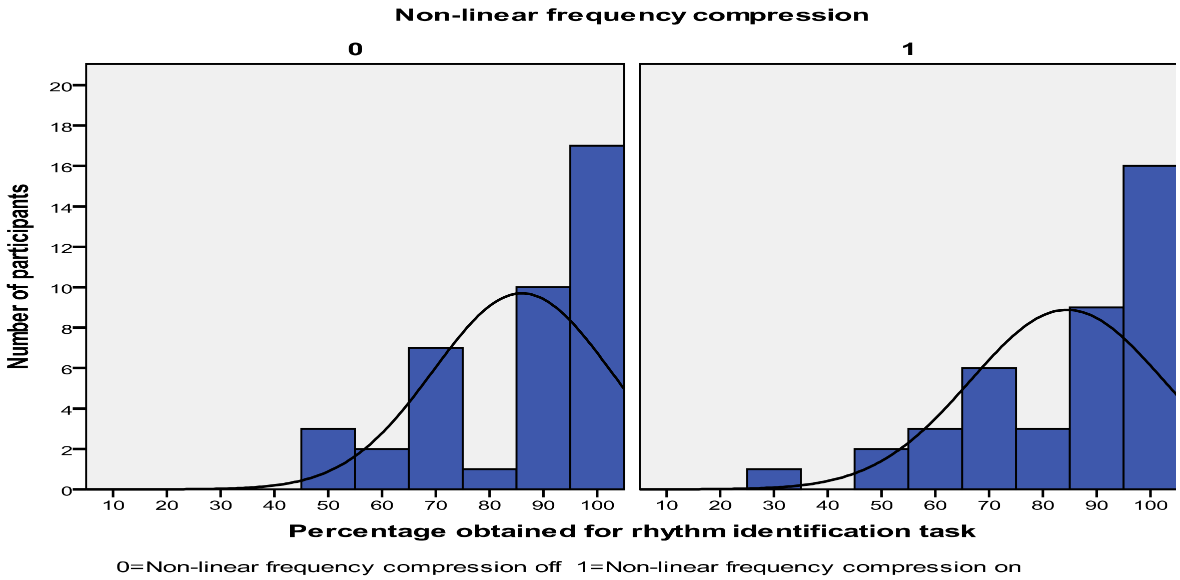

Figure 5-5: Participants' scores for rhythm identification (Sub-test 1) with non-linear frequency compression off versus non-linear frequency compression on

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.

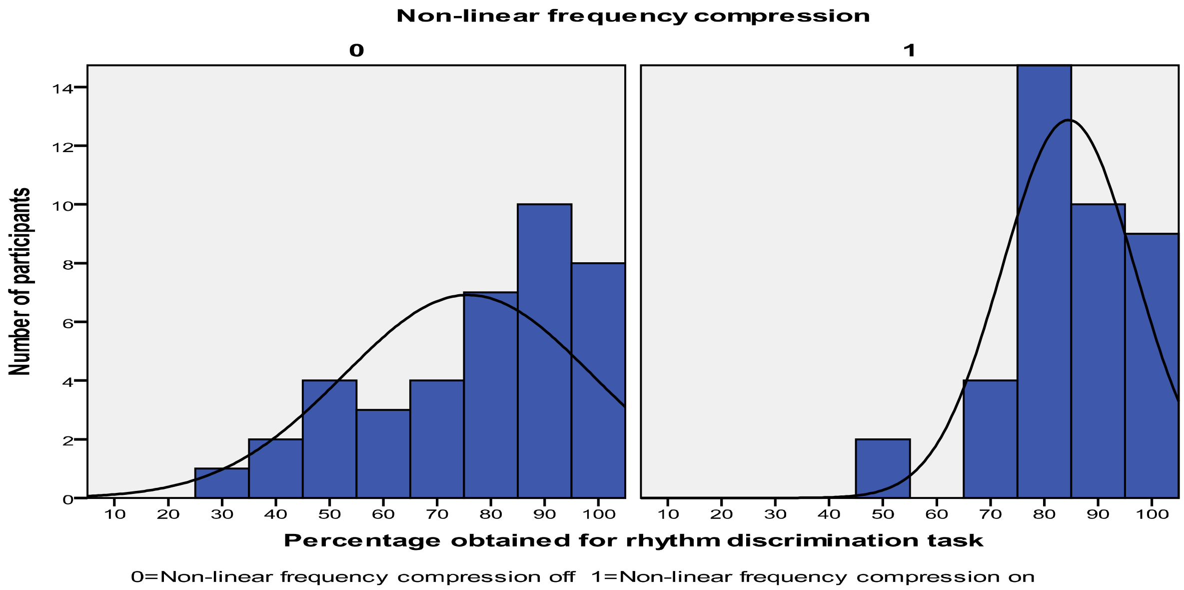

Figure 5-6: Participants' scores for rhythm discrimination (Sub-test 2) with non-linear frequency compression off versus non-linear frequency compression on

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.

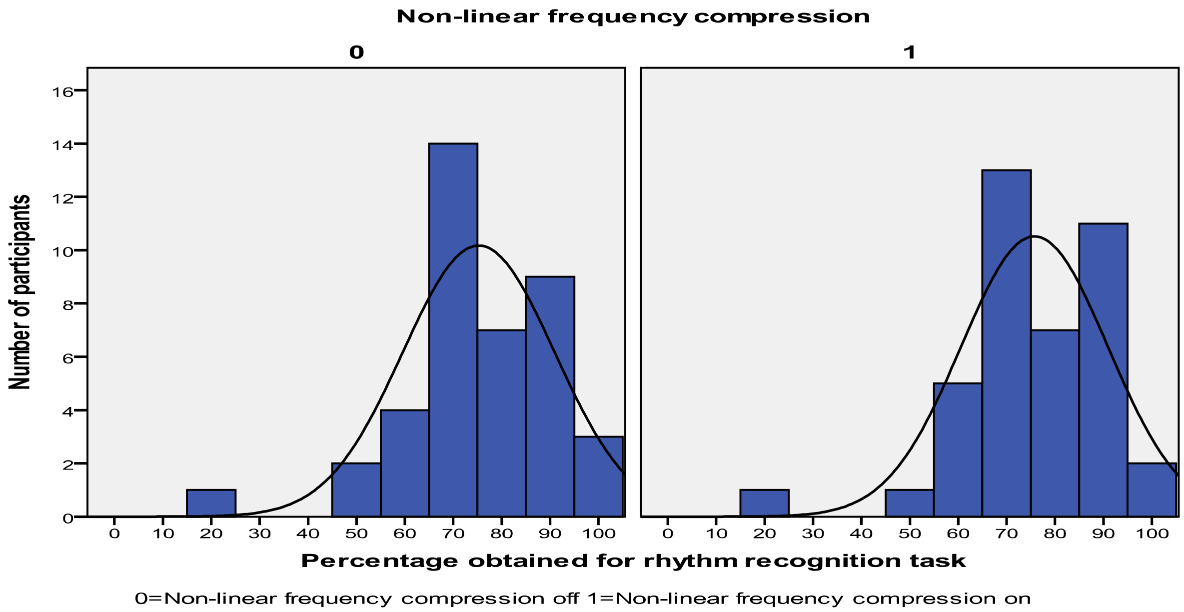

Figure 5-7: Participants' scores for rhythm recognition (Sub-test 3) with non-linear frequency compression off versus non-linear frequency compression on

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.

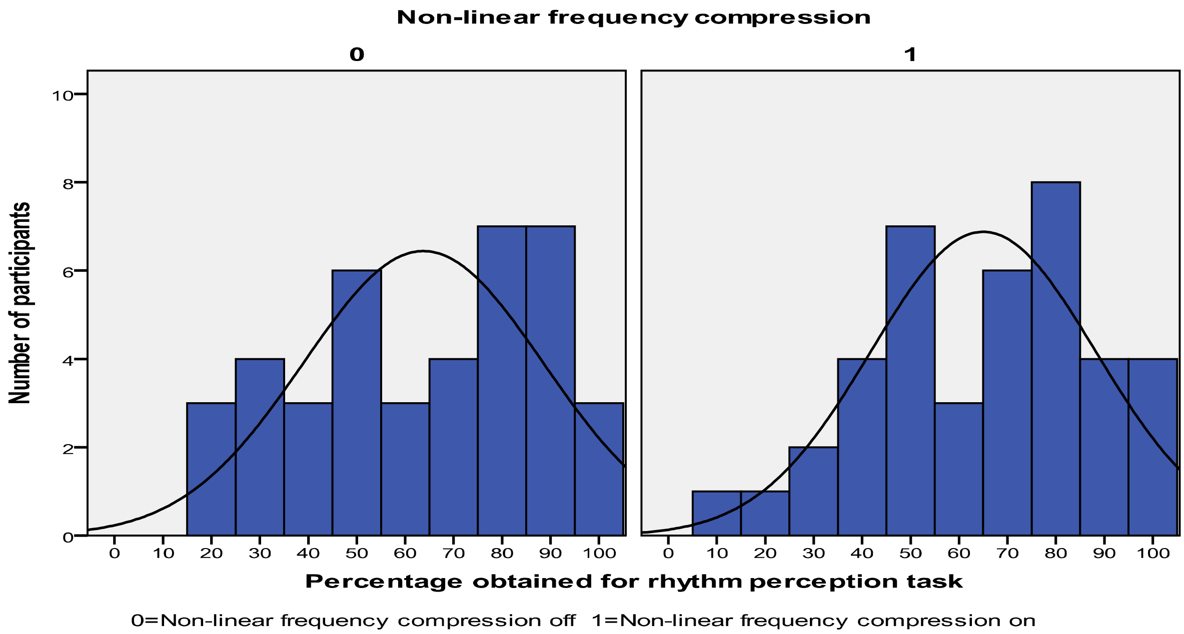

Figure 5-8: Participants' scores for rhythm perception (Sub-test 4) with non-linear frequency compression off versus non-linear frequency compression on

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.

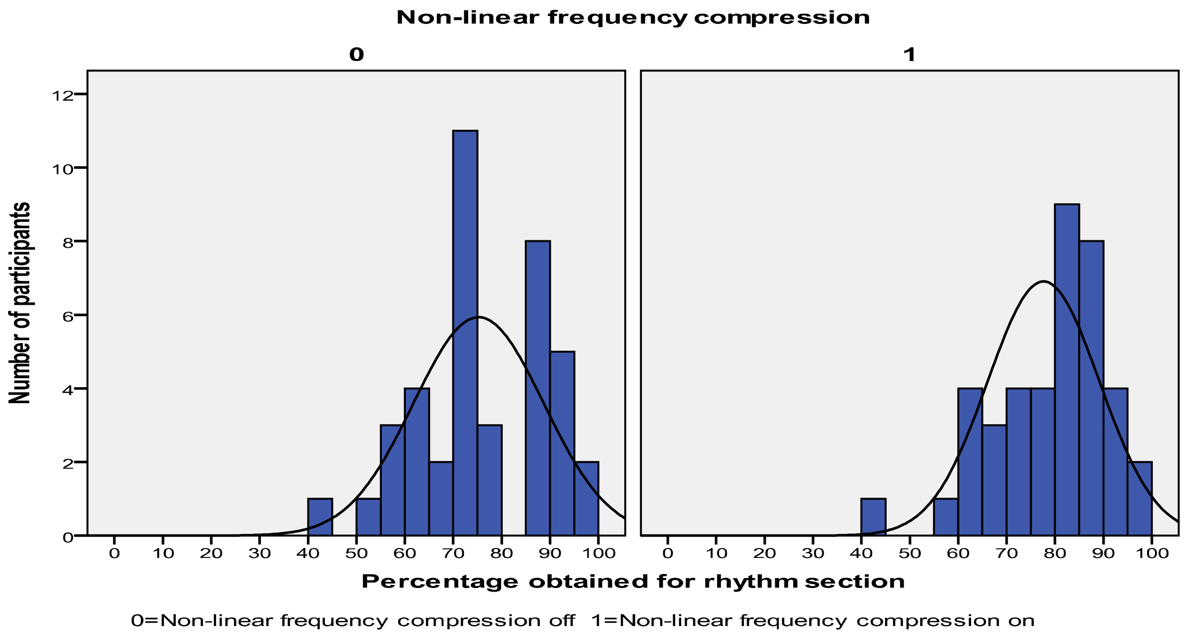

Figure 5-9: Participants' scores for the rhythm section (Section 1) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

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 <u>The influence of non-linear frequency compression on the perception of timbre (Sub-aim 3)</u>

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.

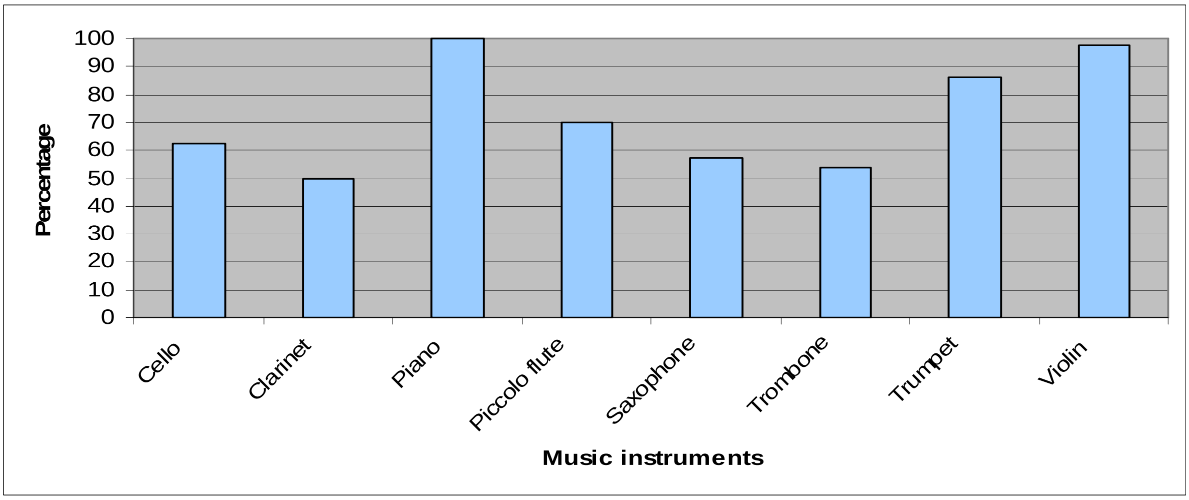

Figure 5-10 Participants familiarity with the musical instruments included in Sub-test 5

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.

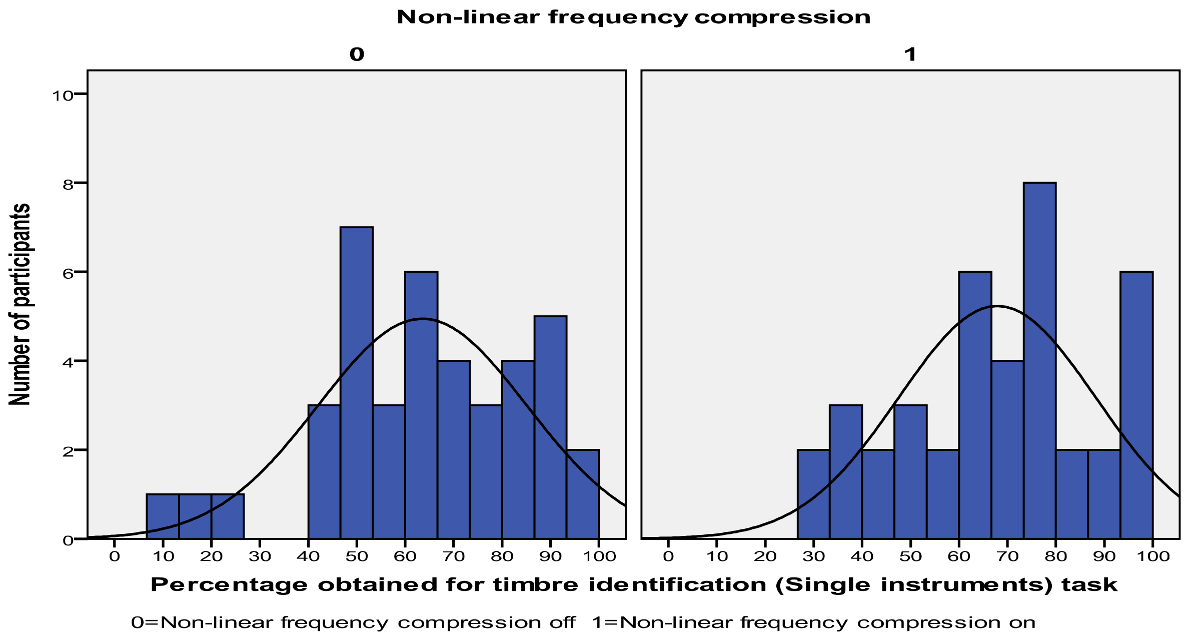

Figure 5-11: Participants' scores for timbre identification (Sub-test 5 – single instrument) with non-linear frequency compression off versus non-linear frequency compression on

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.

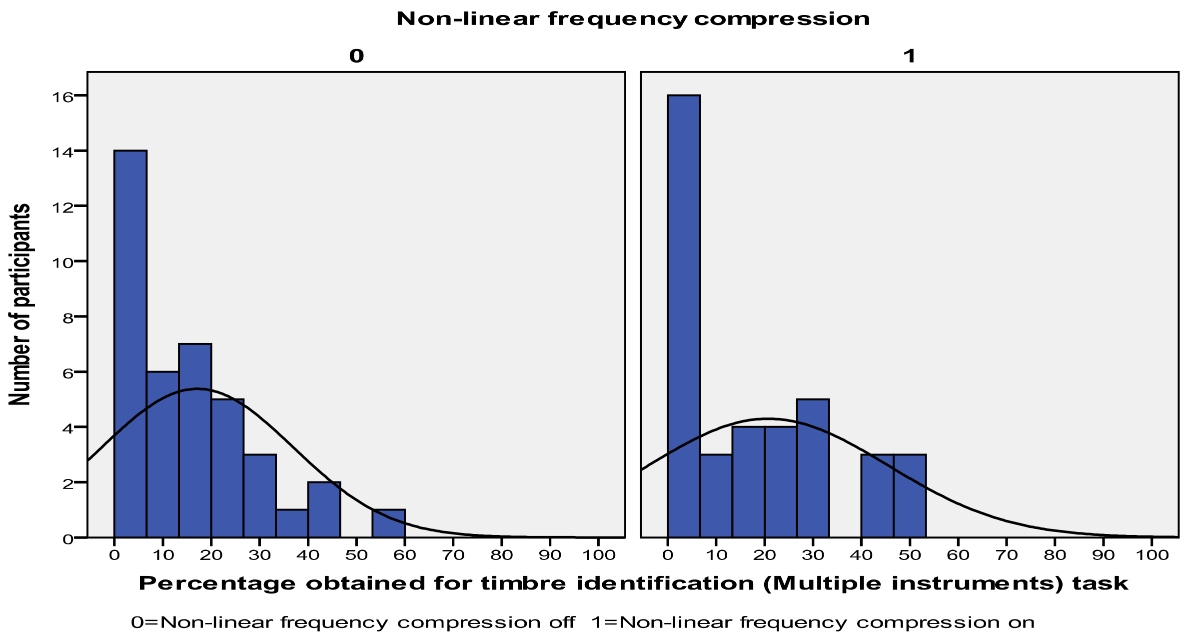

Figure 5-12: Participants' scores for timbre identification (Sub-test 5 – multiple instruments) with non-linear frequency compression off versus non-linear frequency compression on

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.

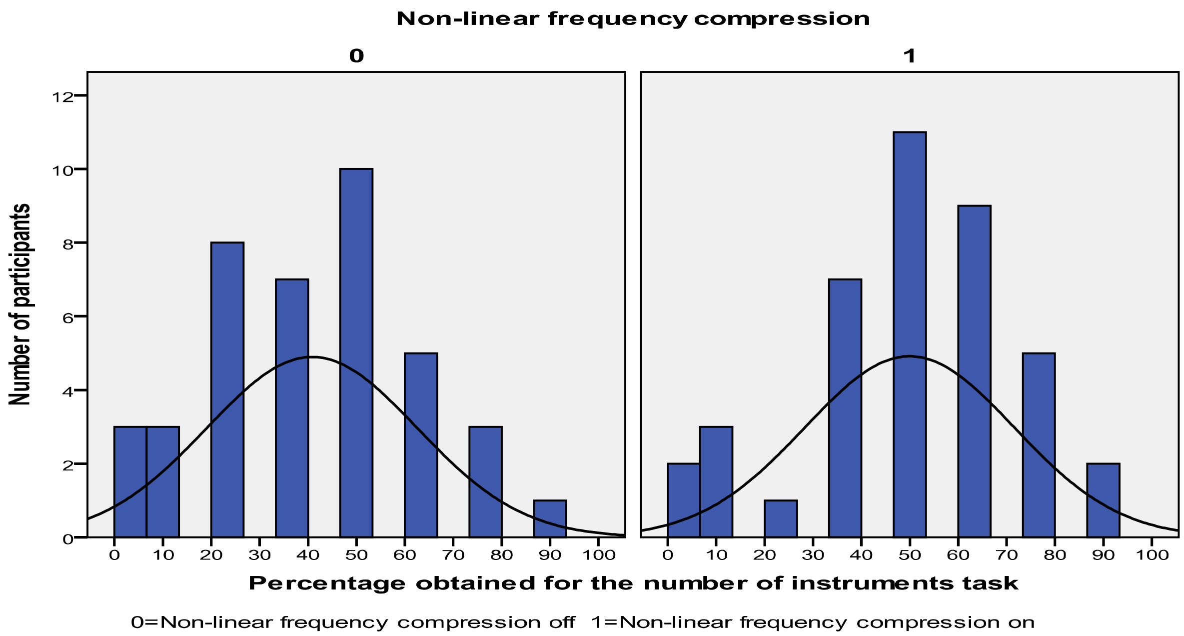

Figure 5-13: Participants' scores for the number of instruments task (Sub-test 6) with non-linear frequency compression off versus non-linear frequency compression on

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.

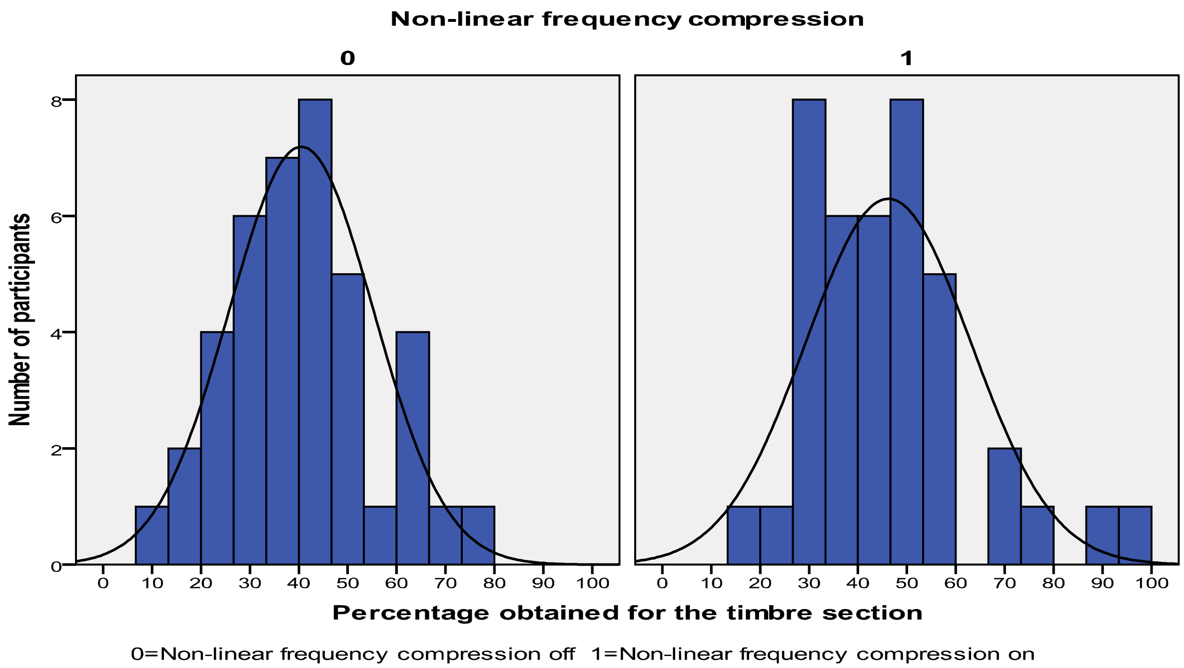

Figure 5-14: Participants' scores for the timbre section (Section 2) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

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.

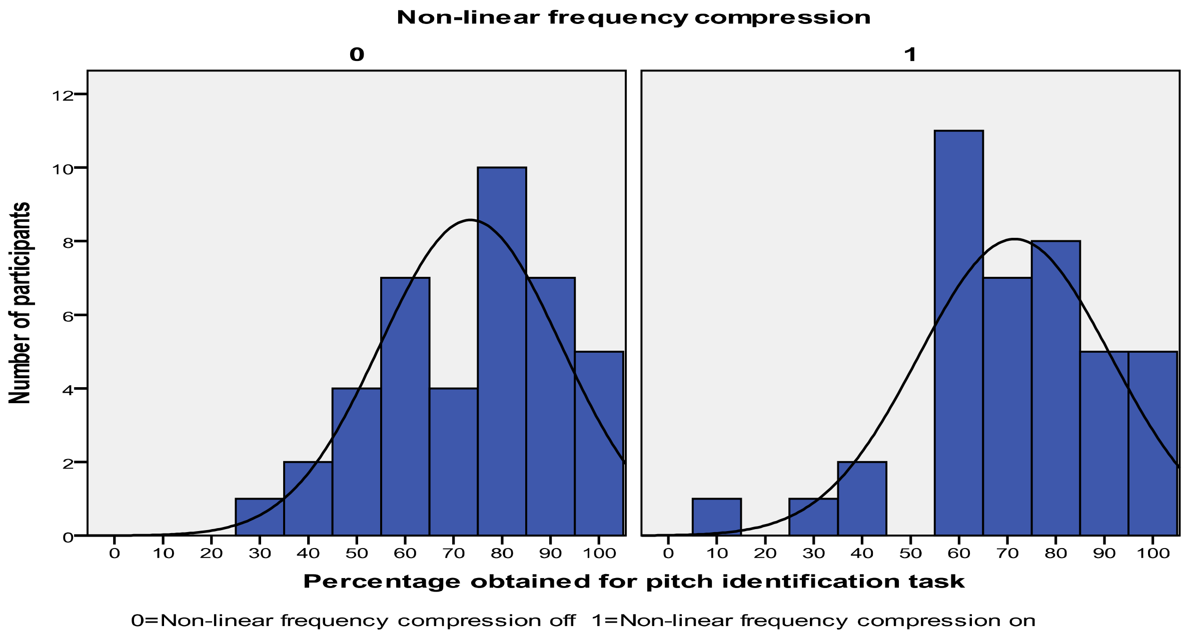

Figure 5-15: Participants' score for the pitch identification task (Sub-test 7) with non-linear frequency compression off versus non-linear frequency compression on

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.

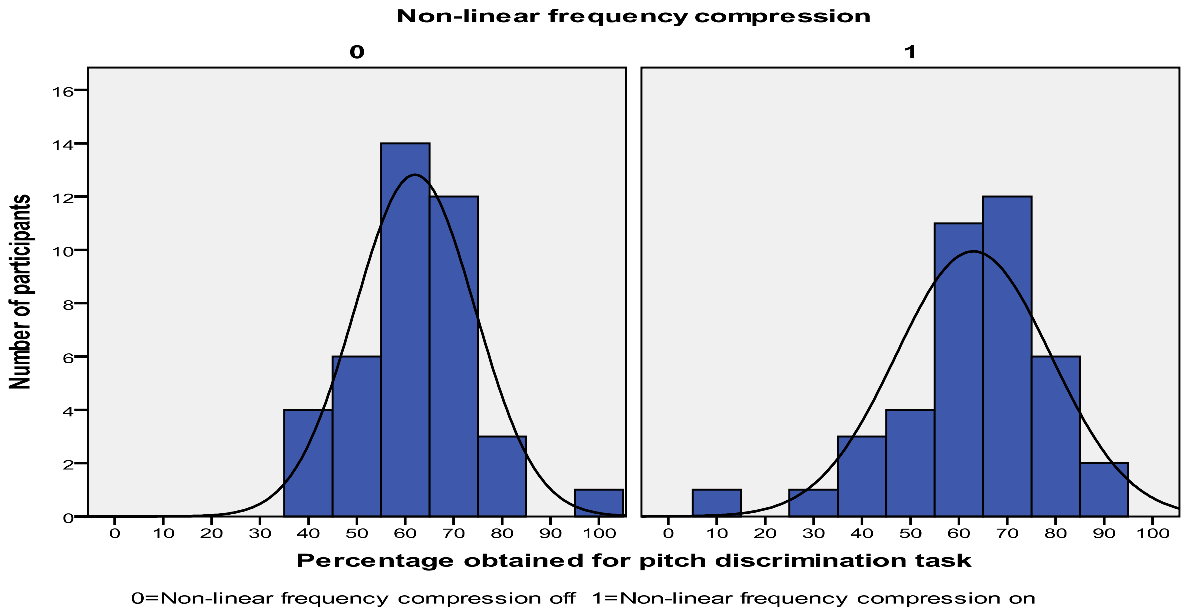

Figure 5-16: Participants' score for the pitch discrimination task (Sub-test 8) with non-linear frequency compression off versus non-linear frequency compression on

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.

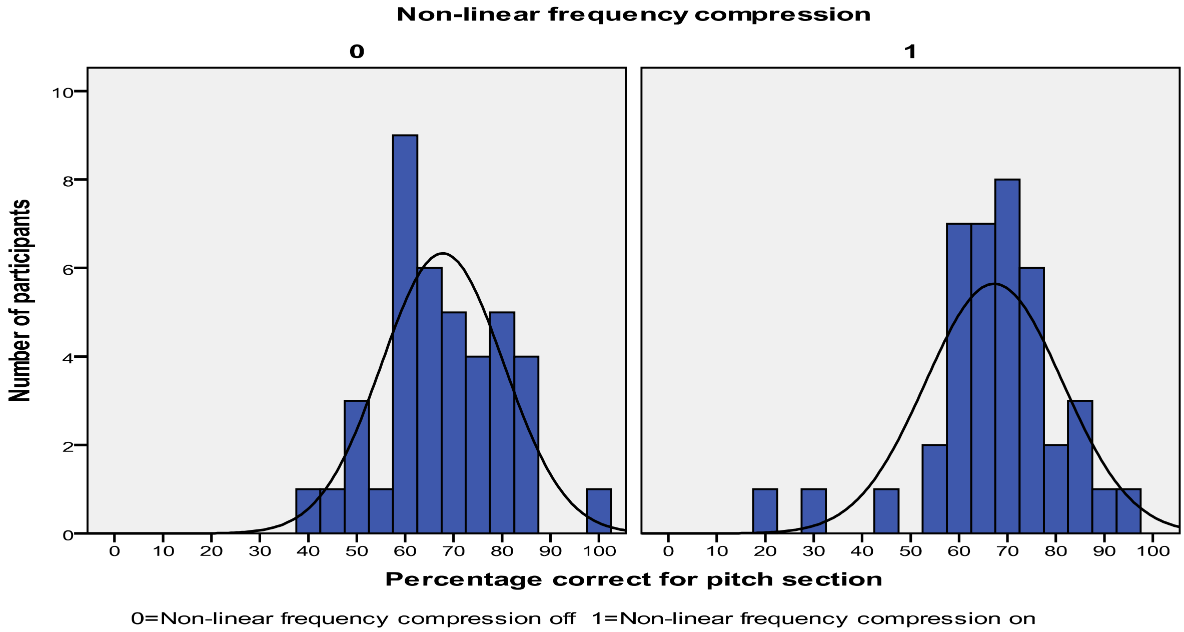

Figure 5-17: Participants' scores for the pitch section (Section 3) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

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 The influence of non-linear frequency compression on the perception of melody (Sub-aim 5)

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.

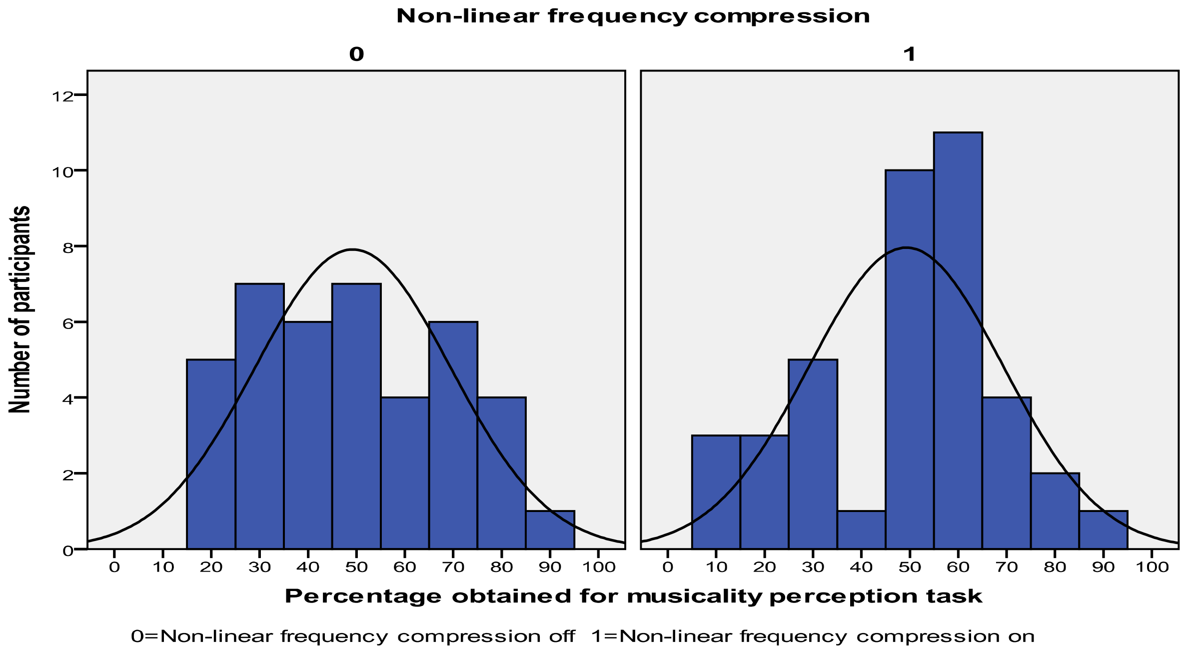

Figure 5-18: Participants' scores for the musicality perception task (Sub-test 9) with non-linear frequency compression off versus non-linear frequency compression on

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.

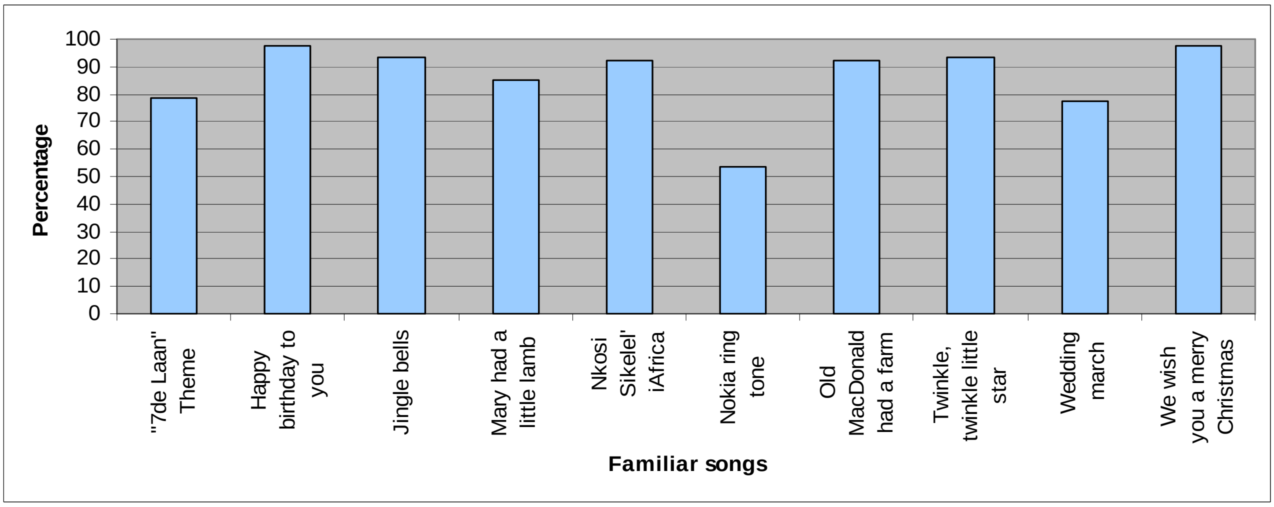

Figure 5-19: Participants' familiarity with the melodies included in Sub-test 10 of the Music Perception Test

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.

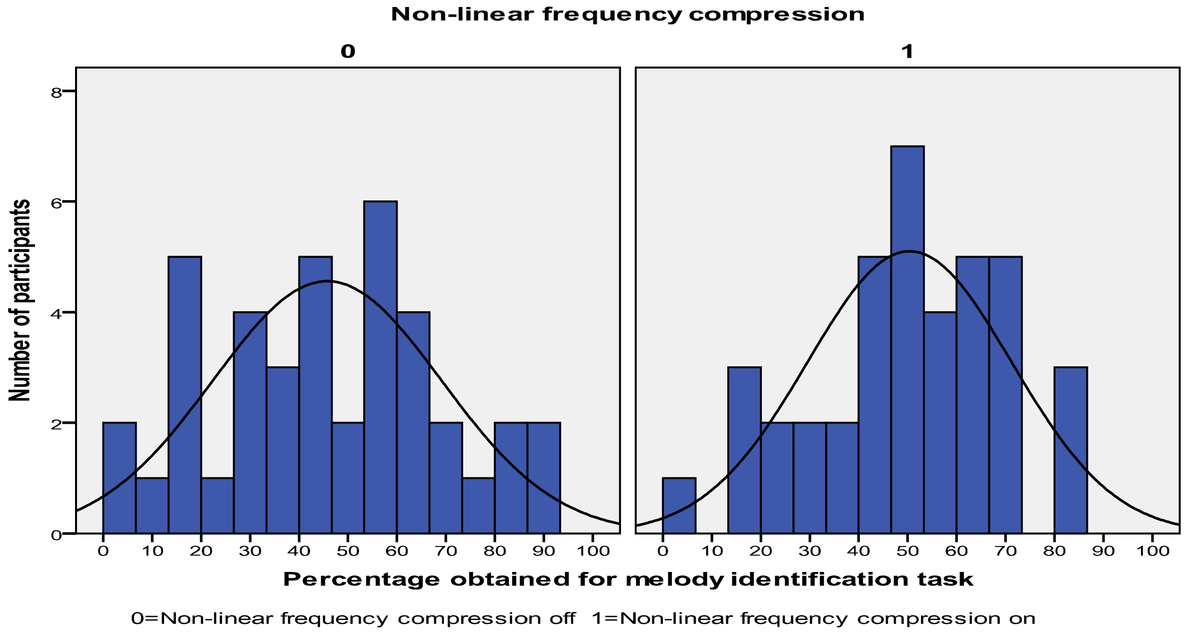

Figure 5-20: Participants' scores for the melody identification task (Sub-test 10) with non-linear frequency compression off versus non-linear frequency compression on

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.

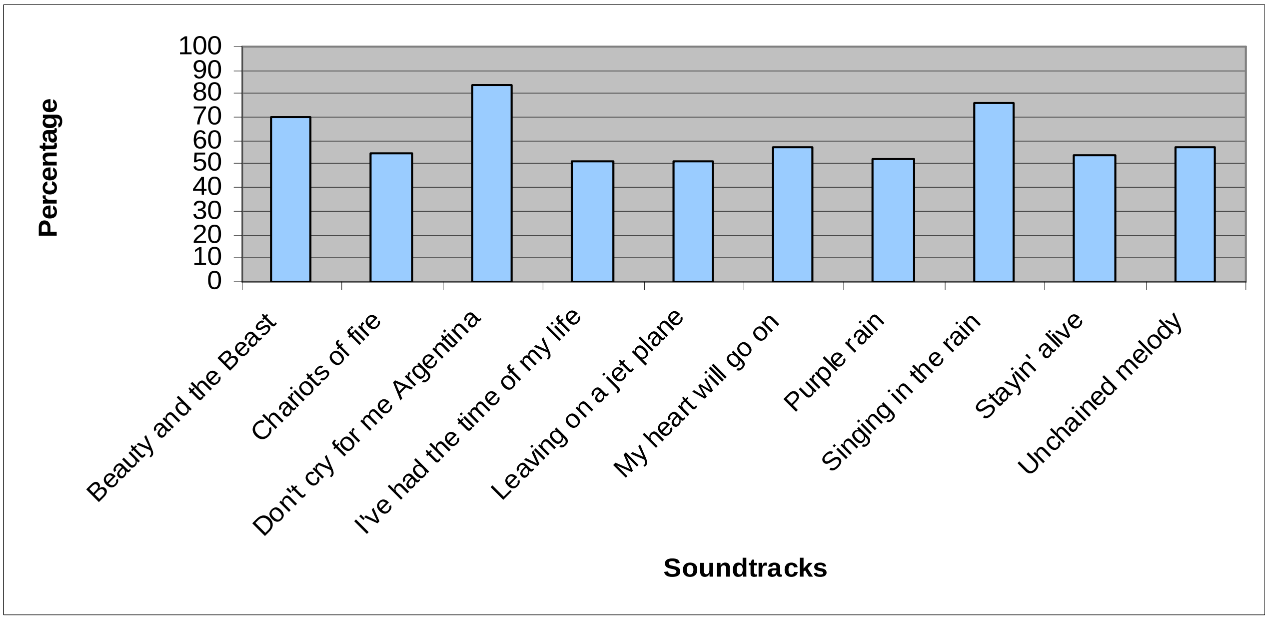

Figure 5-21: Participants' familiarity with the soundtracks included in Sub-test 11 of the Music Perception Test

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.

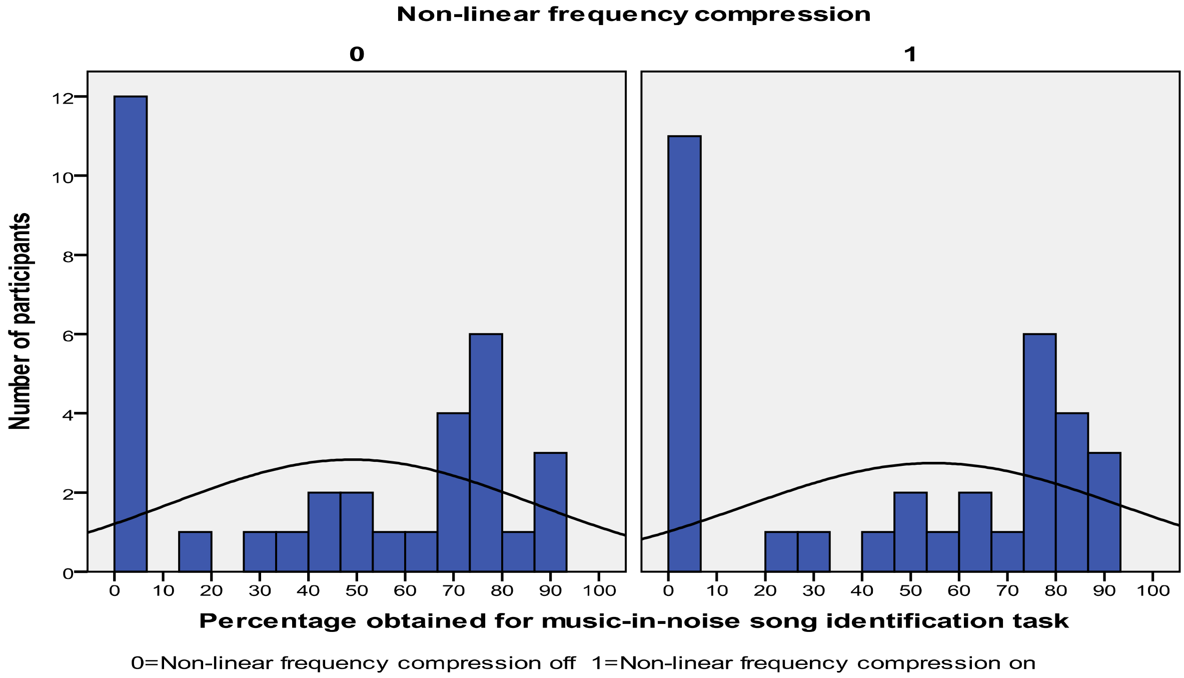

Figure 5-22: Participants' scores for the music-in-noise song identification task (Sub-test 11) with non-linear frequency compression off versus non-linear frequency compression on

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.

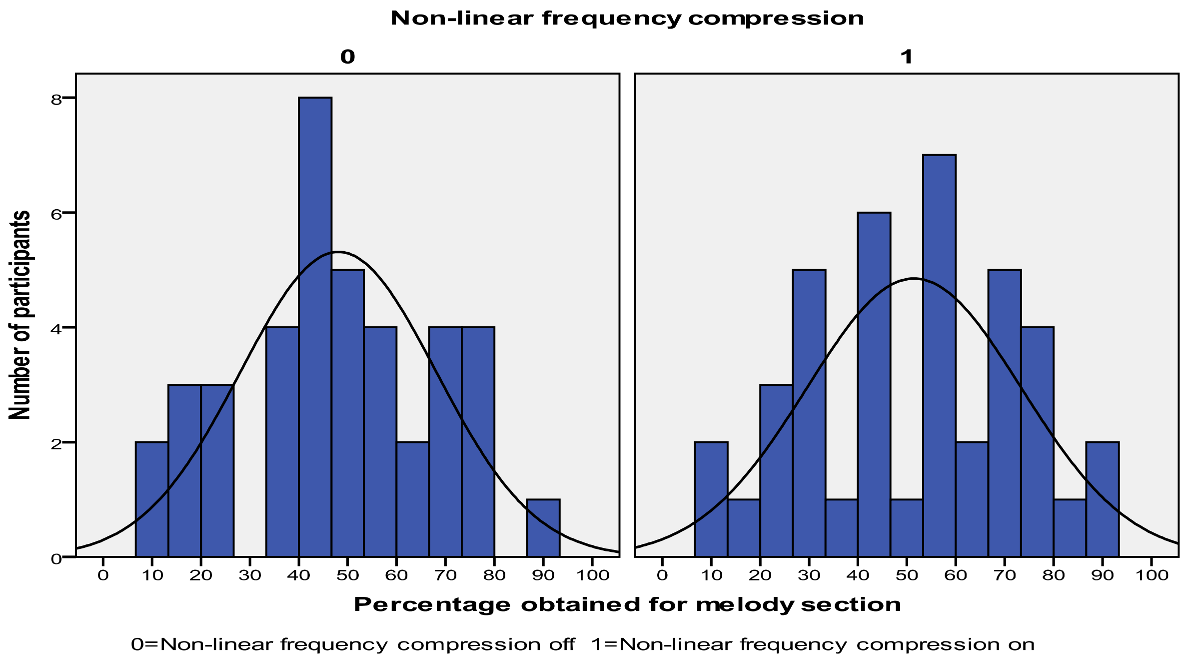

Figure 5-23: Participants' scores for the melody section (Section 4) of the MPT with non-linear frequency compression off versus non-linear frequency compression on

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.

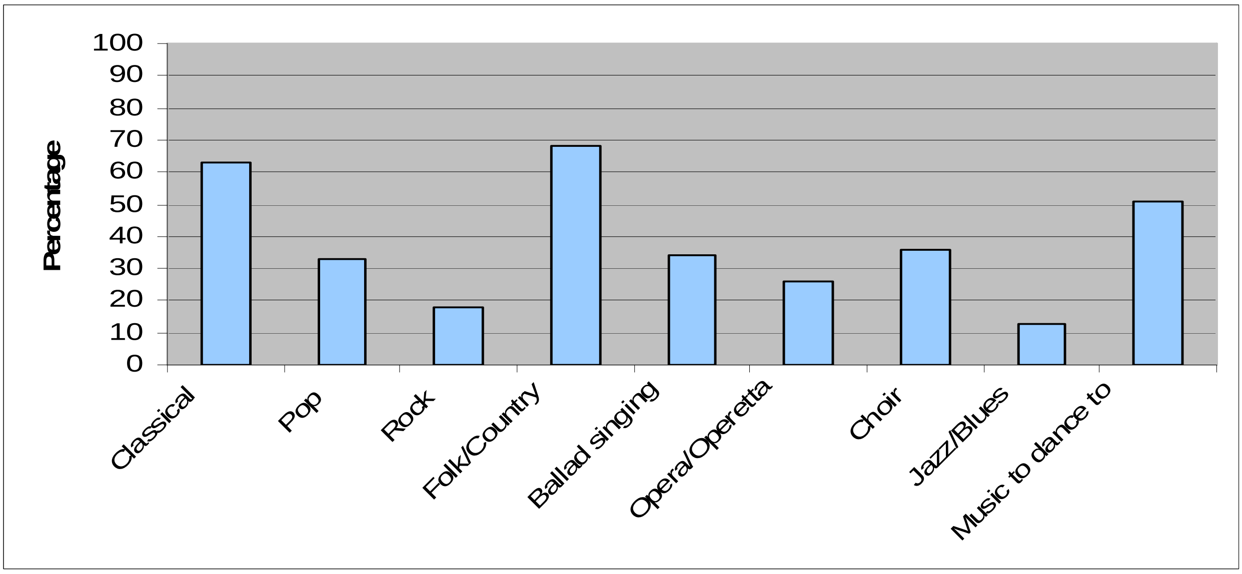

Figure 5-24: Participants' preferences regarding musical genres

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.

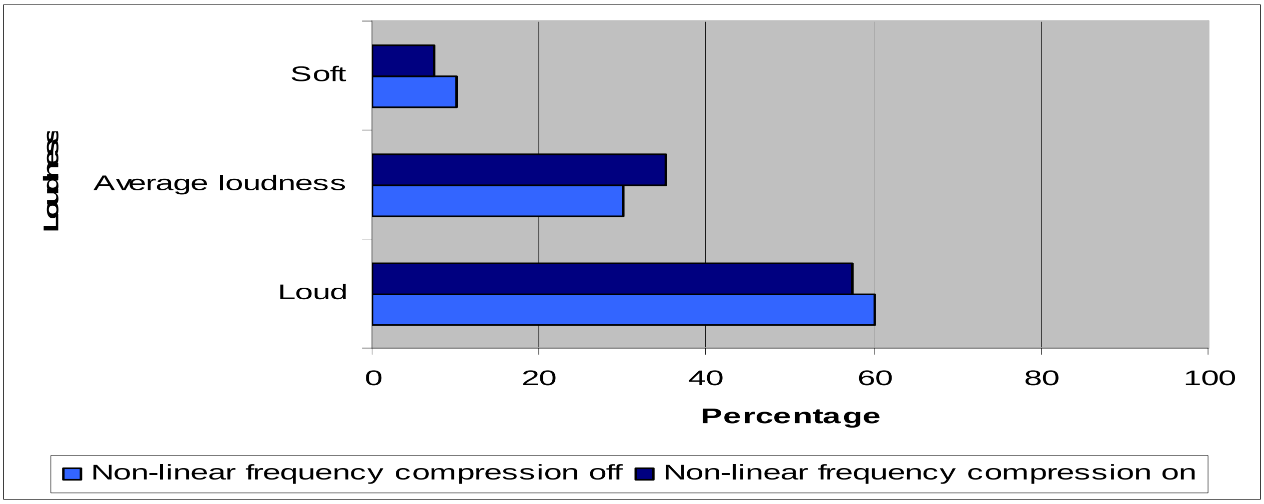

Figure 5-25: Participants' perception of musical loudness with non-linear frequency compression off versus non-linear frequency compression on

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.

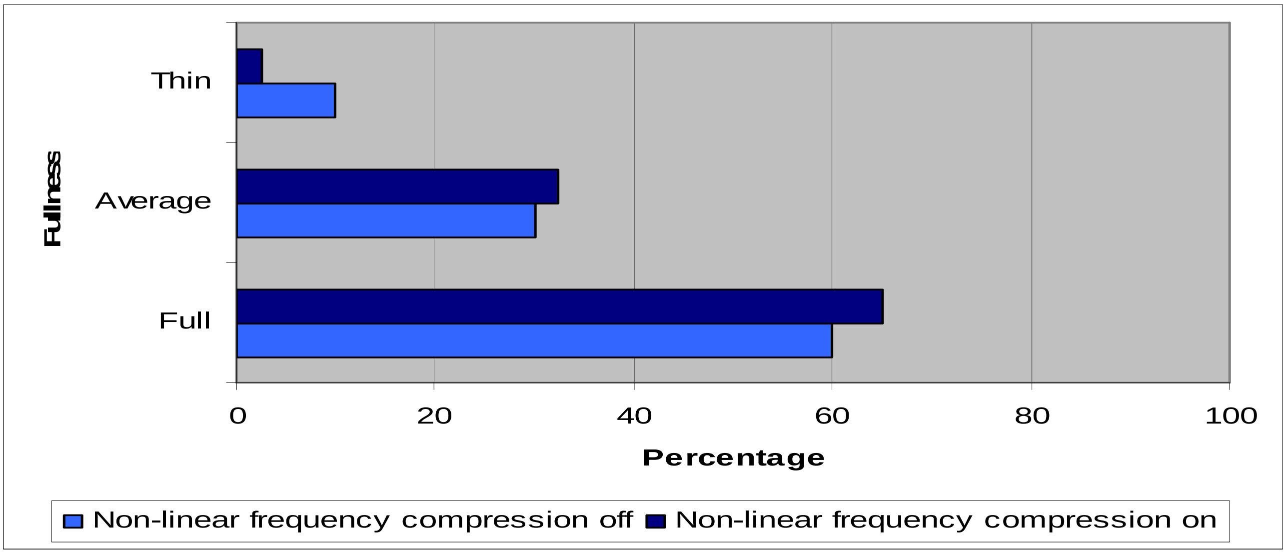

Figure 5-26: Participants' perception of the fullness of music with non-linear frequency compression off versus non-linear frequency compression on

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.

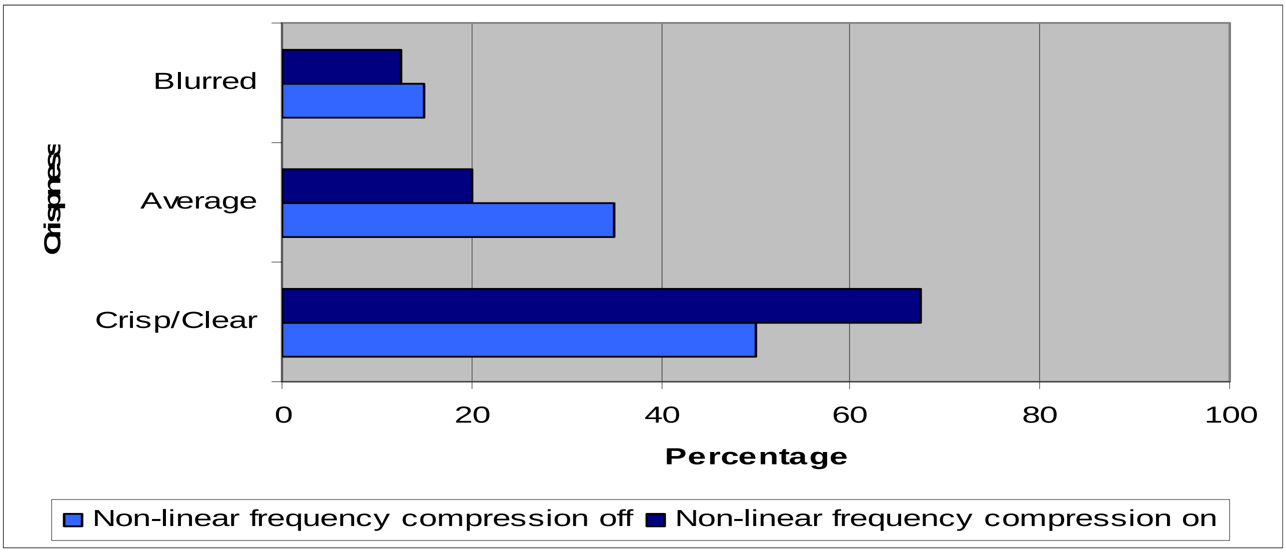

Figure 5-27: Participants' perception of the crispness of music with non-linear frequency compression off versus non-linear frequency compression on

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.

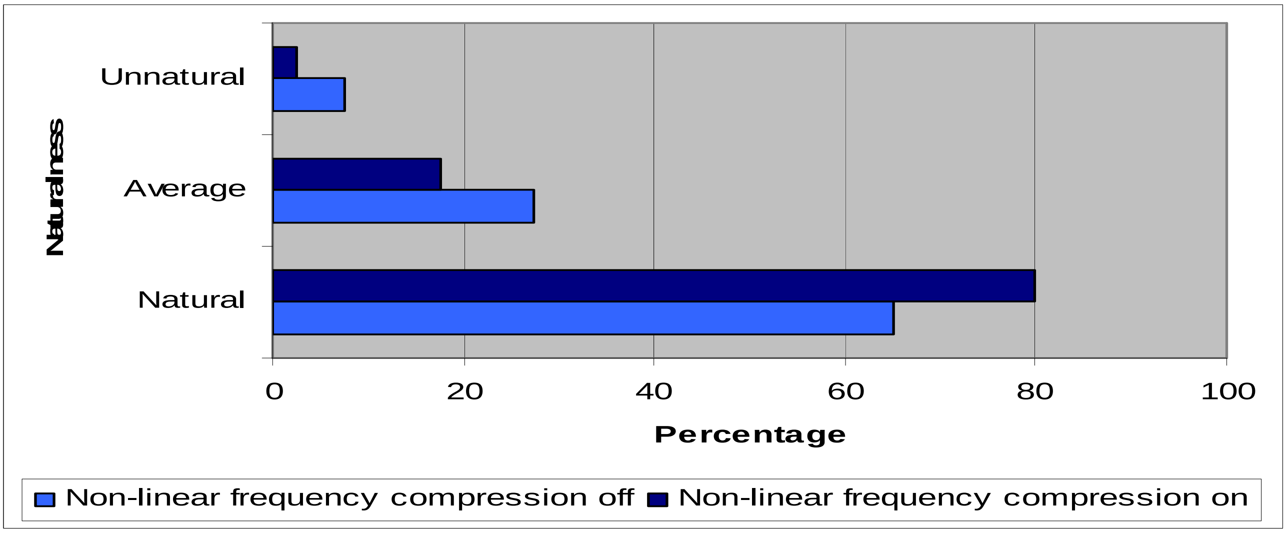

Figure 5-28: Participants' perception of the naturalness of music with non-linear frequency compression off versus non-linear frequency compression on

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.

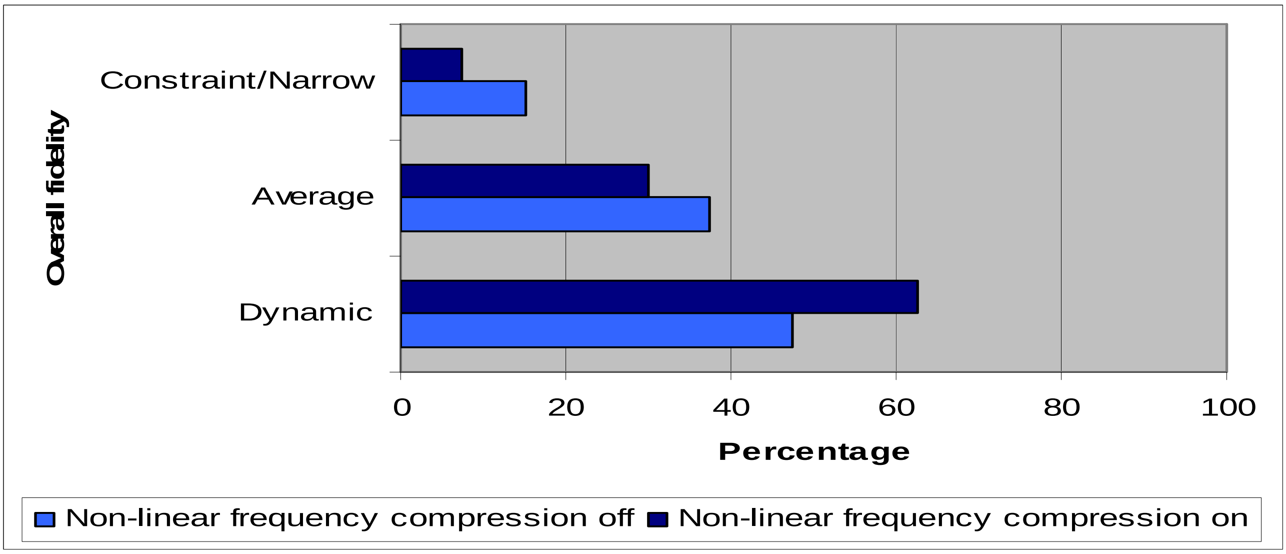

Figure 5-29: Participants' perception of the overall fidelity of music with non-linear frequency compression off versus non-linear frequency compression on

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.

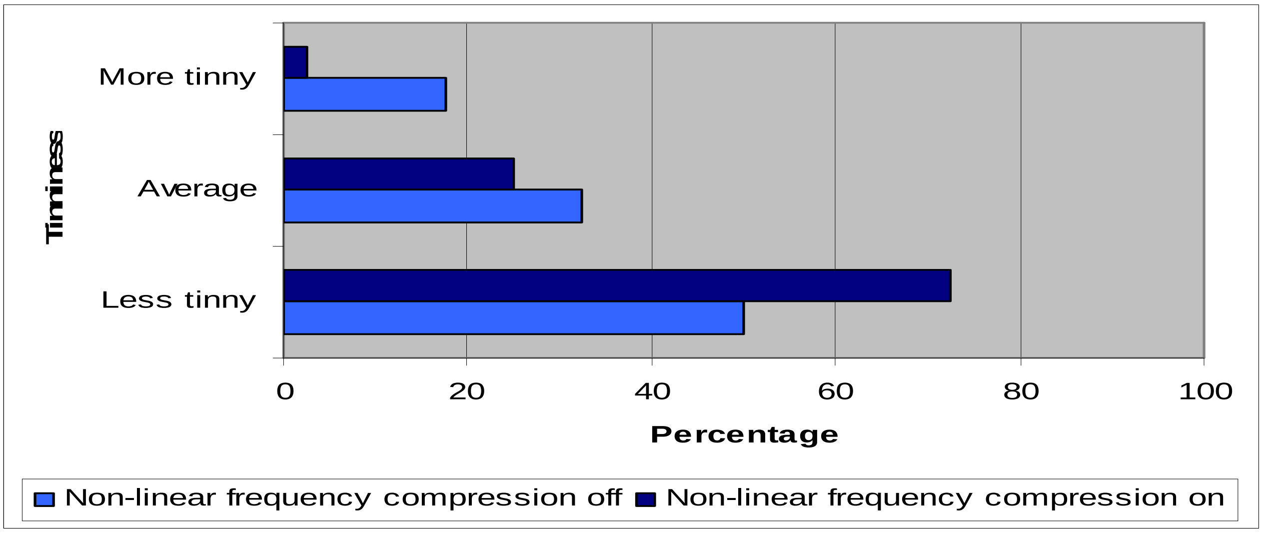

Figure 5-30: Participants' perception of the tinniness of music with non-linear frequency compression off versus non-linear frequency compression on

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.'

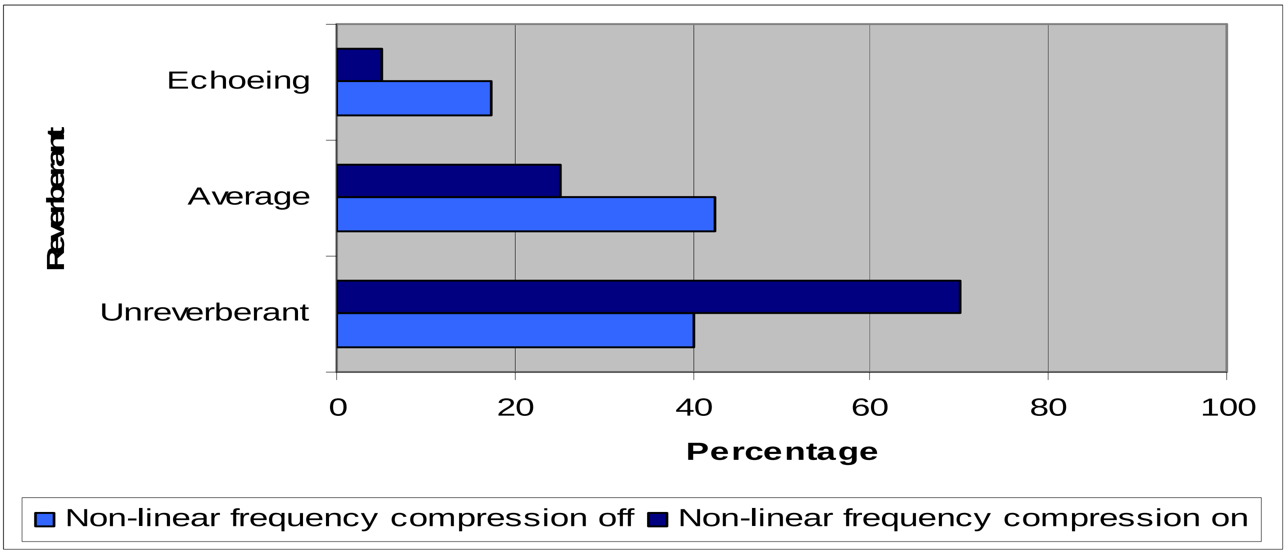

Figure 5-31: Participants' perception of the reverberance of music with non-linear frequency compression off versus non-linear frequency compression on

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.

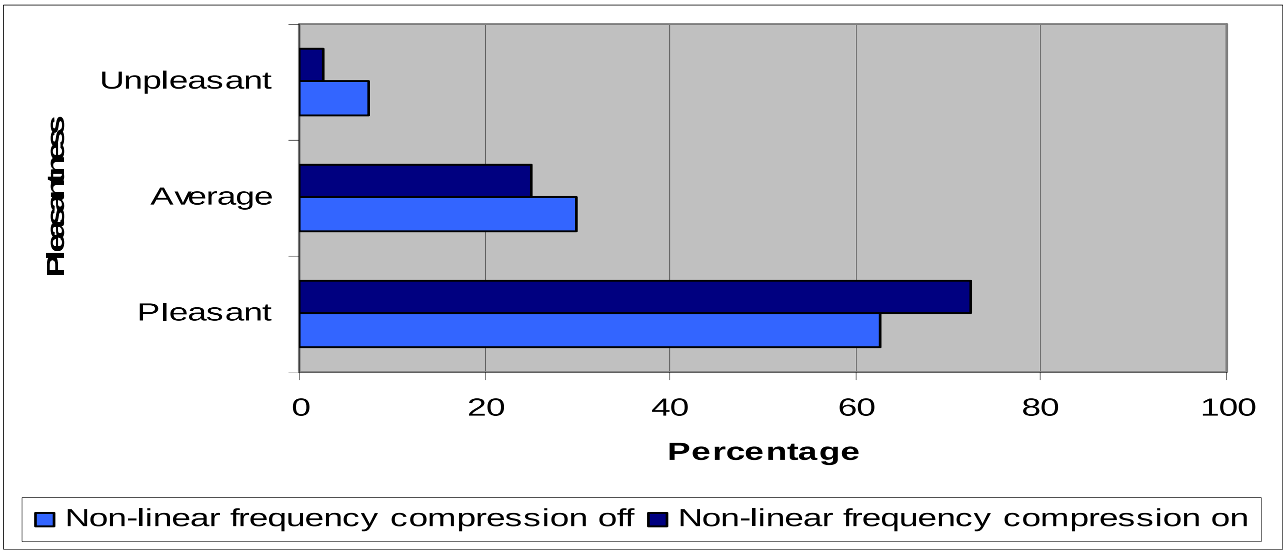

Figure 5-32: Participants' perception of the pleasantness of music with non-linear frequency compression off versus non-linear frequency compression on

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.

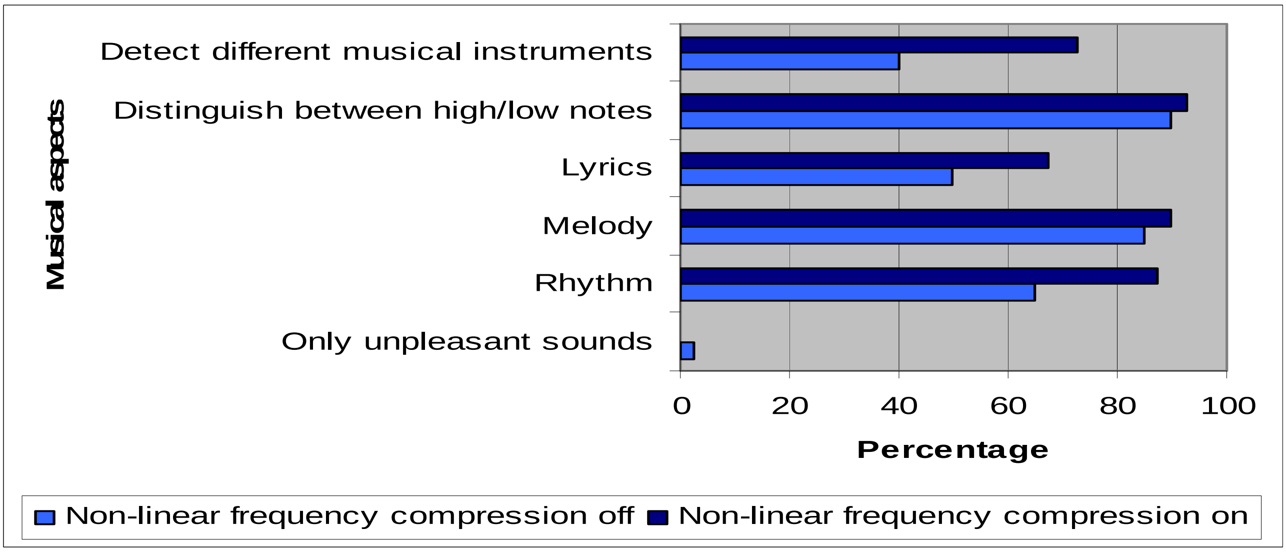

Figure 5-33: Participants' ability to discriminate between different musical aspects with non-linear frequency compression off versus non-linear frequency compression on

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.

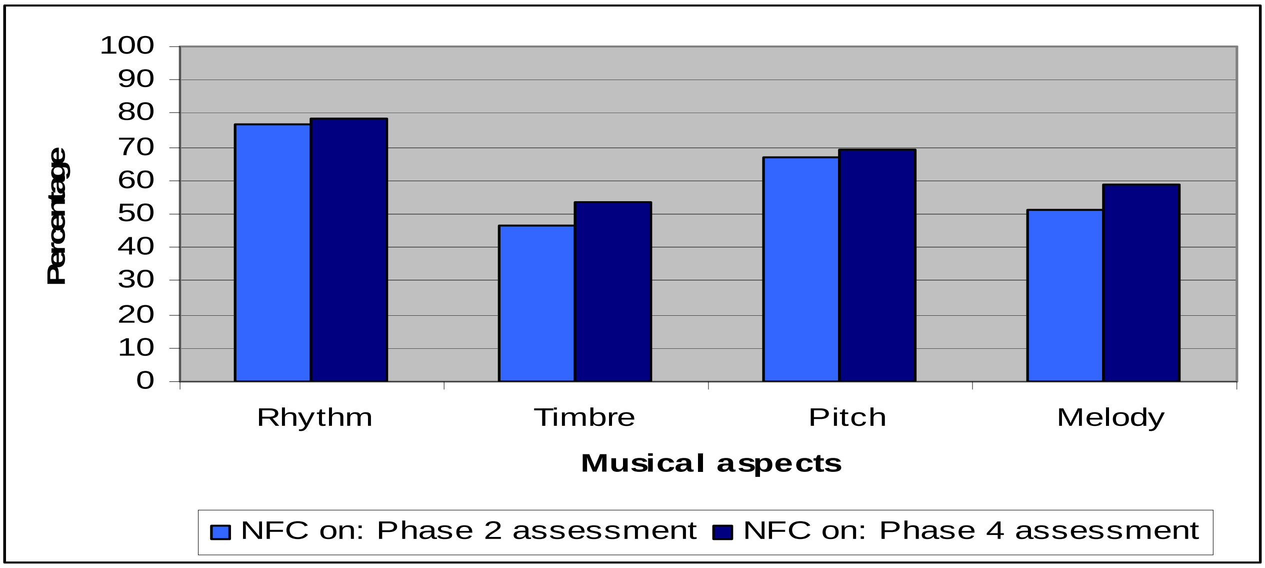

Figure 5-34 Participants' scores for the rhythm, timbre, pitch and melody sections of the Music Perception Test with non-linear frequency compression on during the assessments in Phase 2 and Phase 4

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.

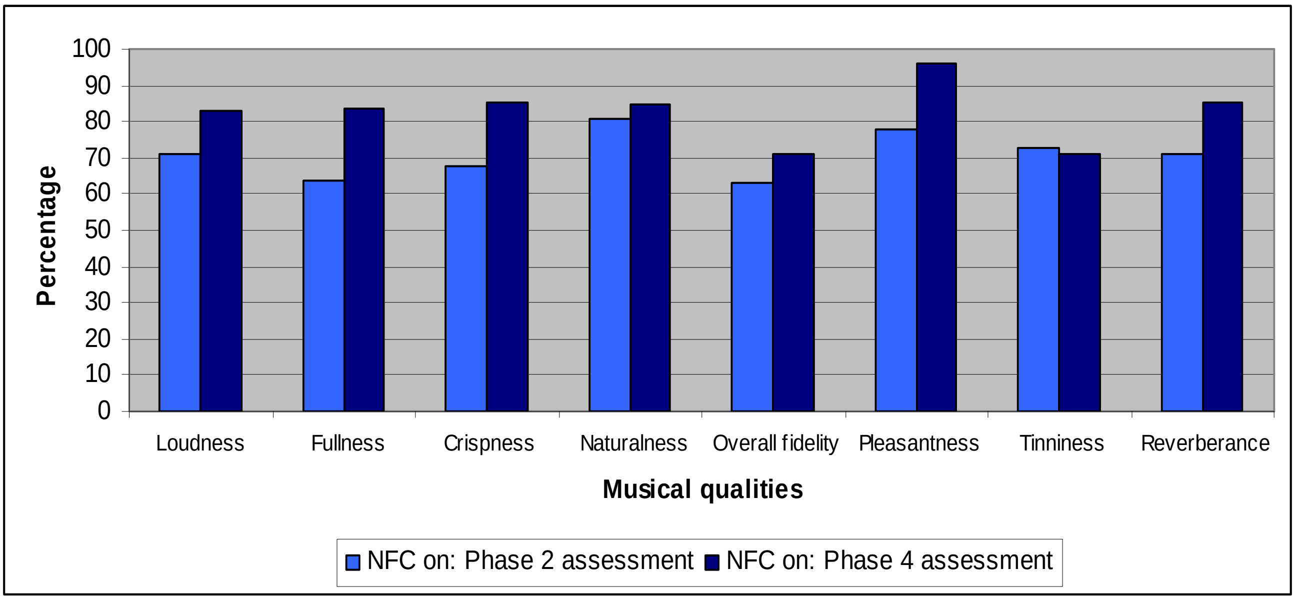

Figure 5-35: Participants' score for the different musical qualities assessed in Questionnaire 2 with non-linear frequency compression on during the assessments in Phase 2 and Phase 4

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.

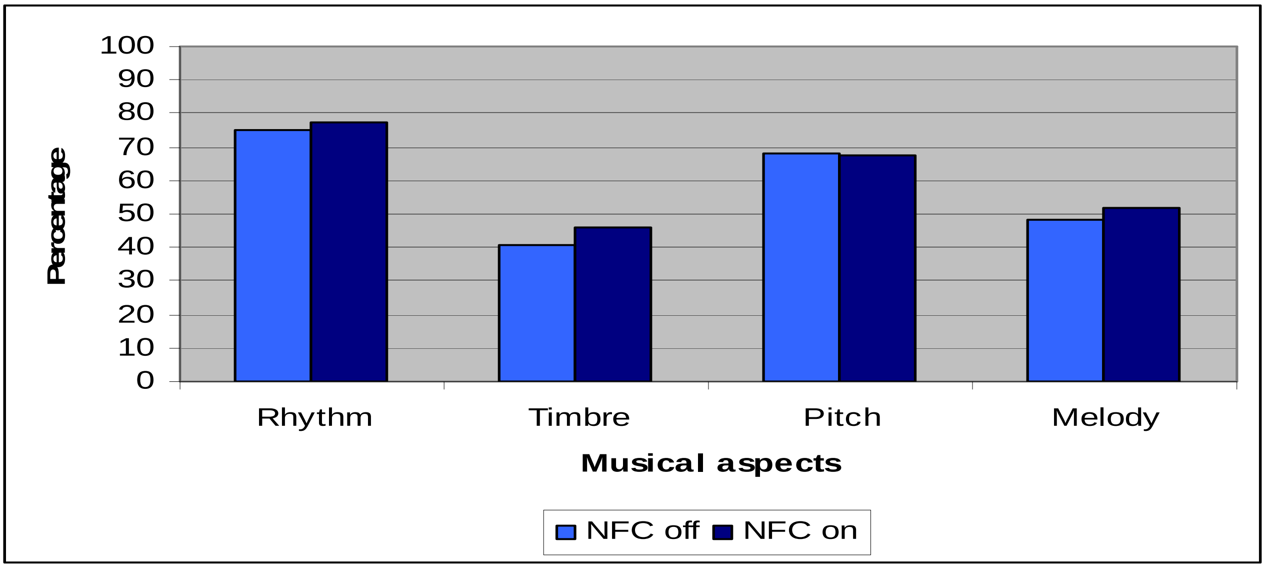

Figure 5-36: Participants' mean scores for the rhythm, timbre, pitch and melody of the Music Perception Test with non-linear frequency compression off and non-linear frequency compression on

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.

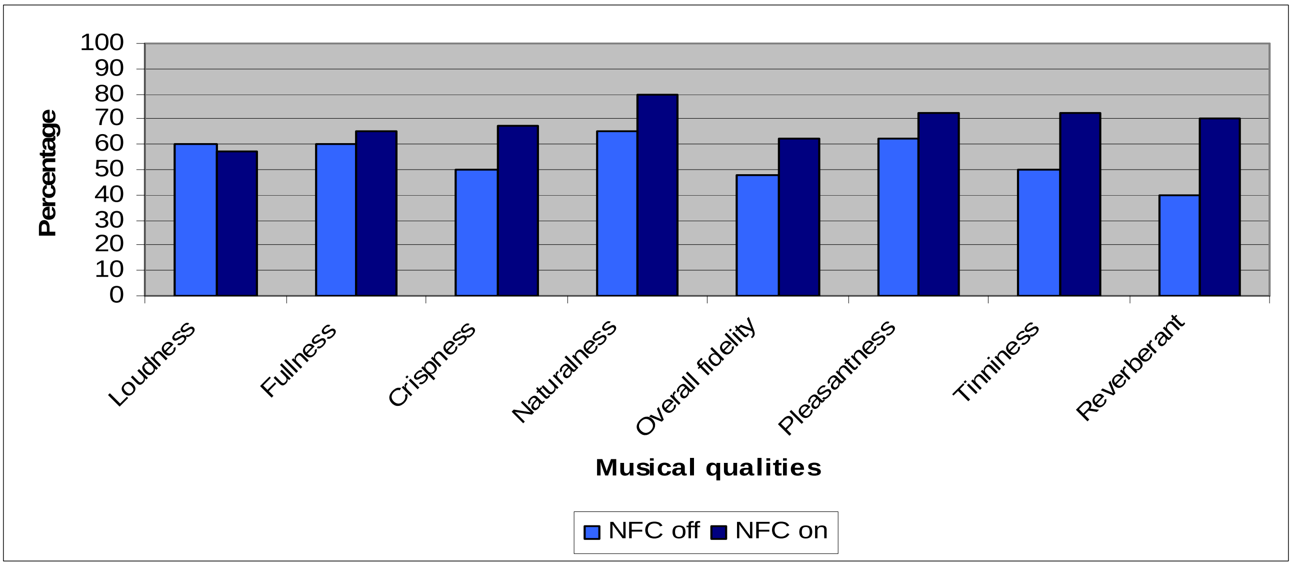

Figure 5-37: Participants' mean scores for the different musical qualities assessed in Questionnaire 2 with non-linear frequency compression off and on

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 on (hours)	NFC off (hours)	Participant	NFC on (hours)	NFC off (hours)	Participant	NFC on (hours)	NFC off (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.