Journal of Communication Disorders, Deaf Studies & Hearing Aids

Uys and Latzel, Commun Disord Deaf Stud Hearing Aids 2015, 3:3
DOI: 10.4172/2375-4427.1000139

Research Article Open Access

Long-Term Effects of Non-Linear Frequency Compression on Performance of Music and Speech Perception

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Rec date: Jun 23, 2015; **Acc date:** Jul 04, 2015; **Pub date:** Jul 13, 2015

Abstract

Objective: Previous studies have already documented improved speech intelligibility and music performance with the use of Nonlinear Frequency Compression (NFC) but as it is widely acknowledged that hearing aid users may gain increasing benefit with longer experience it is interesting to look into long-term effects of this technology. Speech perception benefit with extended use of NFC has been reported for children and cochlear implantees showed a significant improvement in melody recognition after extended use.

Aim: The purpose of this study was to determine the long term effect on the perception of music with NFC in adult hearing aid users and whether speech intelligibility in noise changed with extended use of NFC.

Design and Sample: As real-life use and experience of NFC hearing aids is necessary to reveal its true potential, the study described in this article was performed roughly three years after the initial study to address any long-term aspects and therefore a comparitive research design was implemented. A subgroup of the participants (n=9) of the study described in Uys, Pottas, Vinck and Van Dijk was recruited to check for their music performance and speech intelligibility after 3 years' experience with NFC.

Results and Conclusion: The results confirm the general observation of increased benefit from the hearing devices when making use of the high-frequency cues provided by NFC. Whereas the majority of parameters describing the subjective perception did not change, those parameters relating to the performance - especially melody identification and speech understanding in noise - did improve over the longer period. This leads to the conclusion that it is prudent to intensify the evaluation into the long-term effects of NFC technology.

Keywords: Hearing aids; Non-linear frequency compression; Music perception; Speech perception; Acclimatization

Abbreviations:

NFC: Non-linear Frequency Compression; MPT: Music Perception Test; HINT: Hearing-in-Noise-Test; PPT: Phoneme Perception Test; SR: Sound Recover

Introduction

Music is important! This is true as music enhances the quality of a person's life, not only in terms of enjoyment, but also as a medium that models social structures and provides a medium for human interaction [1-3]. High frequency hearing loss is by far the most common audiometric configuration found in individuals fitted with hearing aids and affects speech comprehension but also music perception adversely as music and lyrics can't be detected or identified easily with only limited access to information located in the high frequencies [4].

Nonlinear Frequency Compression (NFC) is one successful approach to compensate for the deterioration of speech perception associated with reduced high frequency cues [5]. Two studies evaluated the effect of NFC on sound detection and both found that detection was better with NFC than without it [6,7] while other studies investigated the effect of NFC on consonant recognition and found it to be significantly better when NFC was enabled [6-8]. The effects of NFC on speech perception in noise seem to be unclear. Some studies that assessed this outcome found no significant difference in performance with NFC active and inactive at a group level [6,9] while Bohnert et al. [10] reported that seven out of 11 participants had improved speech recognition in noise with the use of NFC but did not indicate whether these improvements were statistically significant. Simpson et al. [11] also found a significant improvement for speech in noise with NFC but only tested five subjects and one subject showed a large improvement which accounted for the mean improvement.

There is also evidence that NFC provides improved music performance [1,2]. These studies indicated that NFC significantly improves hearing aid users' perception of timbre and melody and that it does not influence music perception negatively. Furthermore, it established that the use of NFC significantly improves hearing aid users' perception of the musical qualities of overall fidelity, tininess and reverberance. Participants in this study also preferred the loudness, fullness, crispness, naturalness and pleasantness of music with the use of NFC although these benefits were not significant.

Citation: Uys M, Latzel M (2015) Long-Term Effects of Non-Linear Frequency Compression on Performance of Music and Speech Perception. Commun Disord Deaf Stud Hearing Aids 3: 139. doi:10.4172/2375-4427.1000139

The above mentioned studies however describe the speech and music performance of hearing impaired subjects only for a relatively short time period (about 6 months) after being fit with hearing devices with NFC. But what about the long term effect? As it is widely acknowledged that hearing aid users may gain increasing benefit with longer experience and previous research indicated that children showed continued speech perception benefit after using NFC devices for a year [7] the influence of extended use of NFC on hearing aid users' speech perception should be investigated, especially in noise which are already an area of controversy.

Furthermore, it is known that cochlear implantees demonstrated a significant improvement in their ability to recognize familiar melodies when evaluated again after one year [12] and therefore one should establish whether NFC hearing aid users might also experience the same music perception benefit with their hearing aids. In order to describe these interesting aspects, this study looked into what happen to speech and music perception of the hearing aid user after getting used to the new information provided by NFC when using the devices regularly in real life and after an extended period of use.

Method

Aims

The following aims were stipulated for the current study:

- To determine whether there is a long term effect on the perception of music with NFC in adult hearing aid users without any negative effects on sound quality.
- To determine how speech intelligibility in noise changed when using NFC for a longer period of time (>3years).

Study design

A comparative research design was implemented to investigate whether there were differences between participants' speech and music perception abilities from being assessed in the prior study three years earlier to the assessments of the current study.

Participants

A purposive sampling method was implemented where participants were chosen because they were representative to the topic of interest. All the hearing aid users (n=9) participated in the study described in Uys, Pottas, Vinck and Van Dijk (2013; 2012) [1,2] and were recruited to determine the long term effect of NFC on their music and speech perception. These adults were selected because they bought the NFC devices after the 2011 study and are still using these devices. They met the following criteria (Figure 1):

- Experienced hearing aid users with at least 3 years NFC experience.
- Bilateral, severe to profound, sensory neural hearing loss.
- Age: 26-68 years (mean 55.9 years).
- English language proficiency and literacy.
- Native language: Afrikaans.
- No professional musicians.

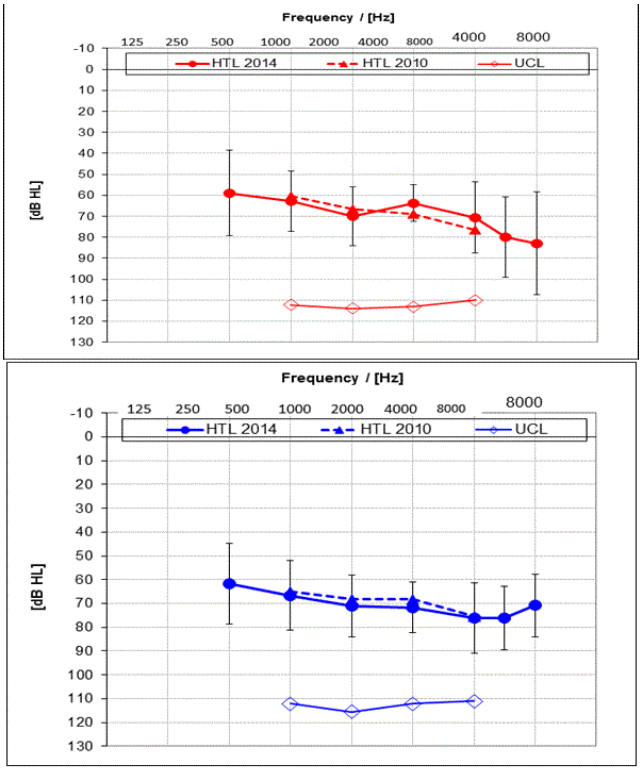

Figure 1: Average hearing loss (and standard deviation) of participants measured in 2010 (Hearing Threshold Level (HTL) 2010) and in 2014 (Hearing Threshold Level (HTL) 2014) for right and left ear.

Material and Apparatus

The same music perception questionnaire and the Music Perception Test (MPT) that was used in the previous study, was used again. The MPT are described in detail in Uys and Van Dijk [13] and a summary is available in Figure 2. To assess participants' speech perception abilities, the Hearing-in-Noise-Test (HINT) [14] and the Phoneme Perception Test (PPT) [15] were performed. The HINT was done in both quiet and noise.

The hearing aids that were used were Phonak Naida III Ultra Power behind-the-ear hearing aids for severe to profound hearing losses. These hearing aids are digital and provide non-linear amplification in the form of multi-band compression [16]. The NFC algorithm used in these hearing aids is referred to as SoundRecover (SR).

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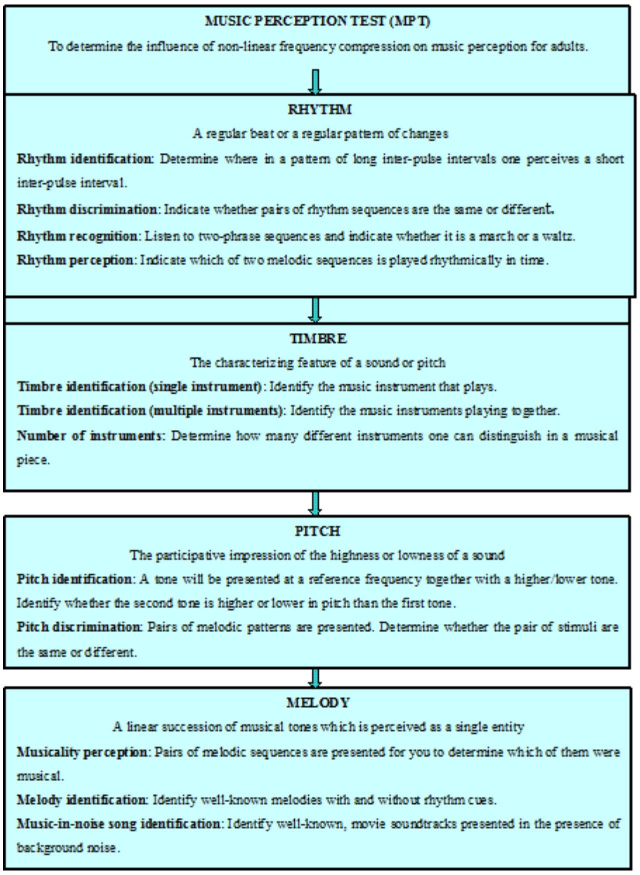

Figure 2: Block diagram of the Music Perception Test (MPT).

Procedure

Participants completed one visit. They first underwent a hearing evaluation to determine their current hearing status which included otoscopic examination, pure tone and speech audiometry. The hearing aids were verified with the Audioscan Verifit and fitted according to the University of Western Ontario protocol [17] to ensure that they were optimized to reflect the current best practice and accurately match the prescribed adult targets provided by the Desired Sensation Level 5.0 (DSL) algorithm. The hearing aids were all previously programmed with a music and speech program and participants were asked to use the music program during the music perception evaluations and the speech program during the speech evaluations. For the music program, all automatic sound features such as noise reduction and adaptive directionality were turned off to prevent these systems from interpreting the music as noise or feedback [18,19].

MPT: The MPT were performed with the hearing aids on the music program. For testing, participants were seated in an audiometric booth, facing the loudspeaker at 45 degrees, at a distance of approximately one meter. The stimuli were played on a Sony D-FJ041 audio player and presented via a Grason-Stadler GSI 61 two channel clinical audiometer to calibrated loudspeakers. The presentation level was 75 dB HL for the calibration tone. The sound level was averaged at 75 dB SPL and participants were permitted to adjust the volume on their hearing aids for maximum comfort. Participants held an answer sheet with a set of written instructions and instructions were also presented via the loudspeakers before the onset of each sub-test. Participants did not receive any feedback after the test.

HINT: The test was performed according to the recommended protocol describe in the test manual [20]. Testing took place in a sound-isolated room where the participant was seated one meter from the loudspeaker. The Sony D-FJ041 compact disc player used to play the test material, output were routed to the two tape inputs of the Grason-Stadler GSI 61 audiometer. The speech was played through one channel and the noise signal through the other channel. The sound room, audiometer and loudspeaker were calibrated before administration of any tests. For testing, an adaptive procedure was used to determine the absolute level (in quiet) or signal-to-noise ratio (in noise) at which the stimulus sentences were correctly identified 50% of the time. For the noise testing, the noise is presented at a fixed level and the sentence levels were varied depending upon the accuracy of the listener's response. The presentation level of each sentence is increased when the response to the previous sentence is incorrect and decreased when the response to the previous sentence is correct. Participants were asked to listen to each sentence and repeat aloud whatever was heard or understood. The same adaptive up-down strategy was followed for testing in quiet.

PPT: The guidelines provided by the PPT manual were followed during testing [20]. The sound system was calibrated prior to testing. The detection test and distinction tests were performed. The detection test detects the level at which a hearing impaired person begins to hear phonemes and the distinction test can reveal the root cause of phoneme confusion weather it being a lack of acclimatization to the hearing instrument settings or reduced distinction capabilities on the side of the instrument wearer.

Data Recording

Test scores were directly written on the answer sheets of the MPT and HINT. The MPT answer sheets were hand scored because individual assessment was required as participants were only assessed on items familiar to them. Results from the PPT were directly entered into the computer while the participant was completing the test. The data from the answer sheets were coded into a Microsoft Excel worksheet.

Results

All participants' audiograms were repeated and it appears that their hearing statuses are, on average, the same after the roughly three years that elapsed (Figure 1). Subjective assessment indicates that the perception of music has been improved only in the dimension called "overall fidelity". The ANOVA analysis revealed no effect on dimension of the subjective assessment of music perception (questionnaire). Moreover, the music perception in general was not influenced negatively with the use of NFC as can be seen in Figure 3.

When using the MPT to test the performance to perceive and process basic musical components, it is evident that acclimatization to get used to rhythm is finished after four weeks. Furthermore it seems that timbre changes slightly but the changes are only significant when compared to participants' performance without NFC. Melody perception however improved significantly as participants got acclimatized to the devices and adapted to make use of the new cues which came audible with NFC.

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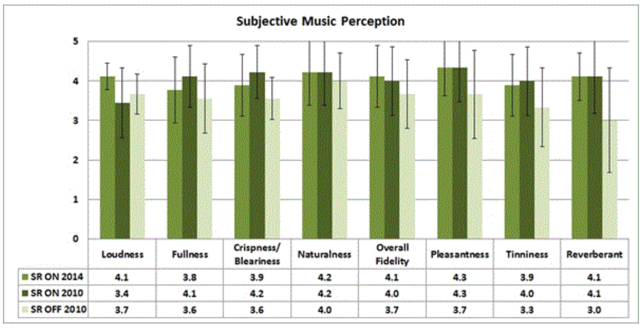

Figure 3: Average results (with standard deviation) of rating of subjective music perception in everyday life. ("0" poor - "5" best performance) all three conditions. SR=Sound Recover (The type of NFC algorithm used in the study hearing aids).

The ANOVA analysis revealed a significant main effect of system (SR ON 2014 compared to SR ON 2010 compared to SR OFF 2010) (F (2, 16)=9,521, p<0.005) of music perception. With the "Post Hoc test for ANOVA" a significant effect is visible for SR ON 2014 compared to SR OFF 2010 (p<0.05) (Bonferroni correction) and with SR ON 2010 compared to SR OFF 2010 (p<0.05) (Bonferroni correction). These results are displayed in Figures 4a-4c.

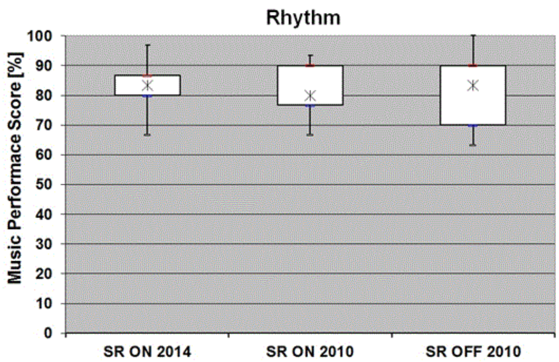

Figure 4a: Rhythm: Music performance scores of three main subscales for all three conditions (median, MIN/MAX/25- and 75-quartiles) (*statistical significant on a 0.05 level)

With regards to the long term effect of NFC on speech perception, the PPT shows a reduction of the detection threshold (10 dB at 6 kHz and 6 dB at 9 kHz) with statistical significance as can be seen in Figure 5. The ANOVA analysis revealed a significant main effect of system (SR ON compared to SR OFF compared to Unaided) (F(2, 14)=284,09, p<0.000) and a significant main effect of frequency (300 Hz ó 500 Hz ó 6 kHz ó 9 kHz) (F(3, 21)=41,765, p<0.000) of the detection threshold test of the Phoneme Perception Test. A significant effect could be shown with the "Post Hoc test for ANOVA" for SR ON compared to SR OFF (p<0.05) (Sidak correction), for SR ON compared to Unaided (p<0.000) (Sidak correction) and for SR OFF compared to Unaided (p<0.000) (Sidak correction).

Additional PPT measurements revealed less confusions comparing NFC activated versus NFC deactivated.

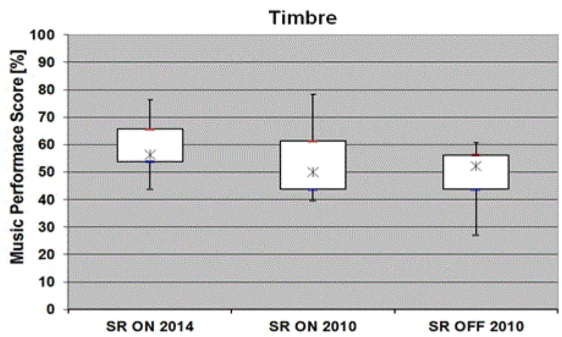

Figure 4b: Timbre: Music performance scores of three main subscales for all three conditions (median, MIN/MAX/25- and 75-quartiles) (*statistical significant on a 0.05 level)

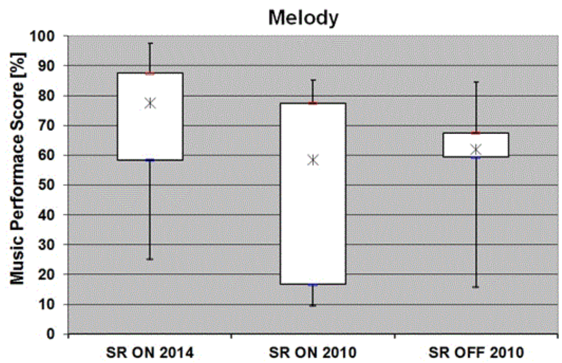

Figure 4c: Melody: Music performance scores of three main subscales for all three conditions (median, MIN/MAX/25- and 75-quartiles) (*statistical significant on a 0.05 level)

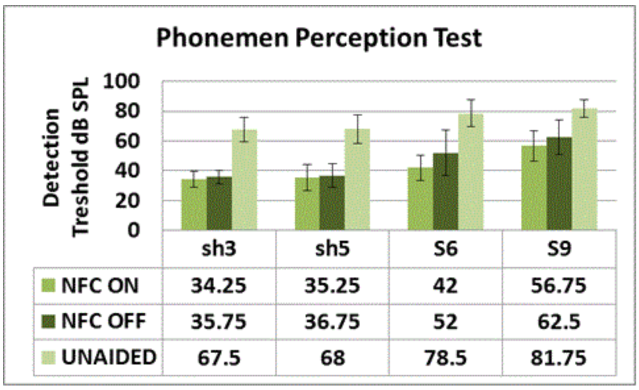

Figure 5: Detection threshold measured with the PPT (mean values and standard deviations) (*statistical significant on a 0.05 level)

Consistent with a couple of other studies, NFC improves speech understanding in quiet. The HINT means show 8% improvements but with no statistical significance. With the HINT in noise, speech recognition is improved with NFC by about 5 dB but again this is not statistically significant. For speech in noise, perception of five participants improved, one participant's perception deteriorated and for three participants no result could be obtained. These results are displayed in Figure 6.

PPT study 1.

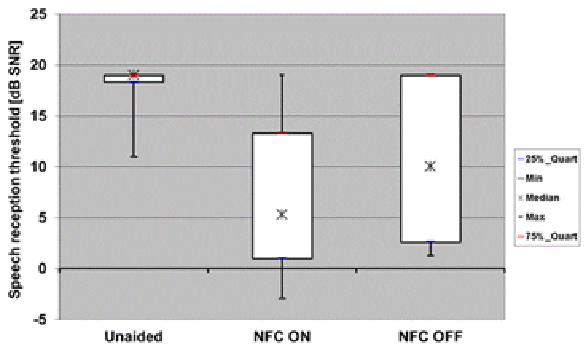

Figure 6: Speech recognition threshold measured with HINT for the conditions NFC ON, NFC OFF and unaided (median, MIN/MAX/25- and 75-quartiles) (*not statistical significant).

Figure 7 displays the results of the distinction test. Although the benefit obtained with SR is not statistically significant, it is clear that participants' distinction is not worse with the activation of SR.

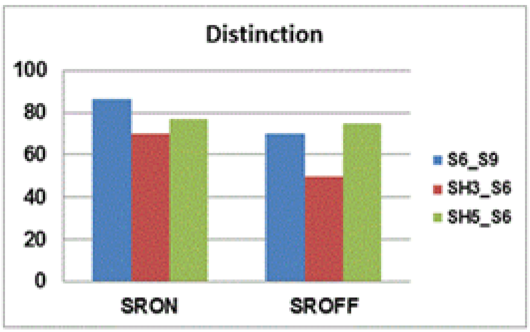

Figure 7: Distinction test results.

Discussion and Conclusion

Given the small sample size, it is interesting to see that some effects of experience with NFC were seen. It seems that the additional cues provided by NFC become helpful after lengthy acclimatization in identifying melodies and the way music is perceived. Participants showed a definite preference for the overall fidelity of music after an extended period of time meaning that they find music more dynamic and less constrained or narrow after an extended acclimatization period. This reflects that participants are more comfortable with the additional sound provided by NFC and that they learned to enjoy the extended range it adds to their musical experience. After the extended acclimatization period, participants were better able to identify melodies than before. A similar tendency was found with cochlear implantees who showed a significant improvement in their ability to recognize familiar melodies when evaluated again after one year [12]. One can therefore conclude that melody recognition seems to continue to improve with extended use of amplification devices. As repetition and learning may improve one's performance on certain tasks or tests, it should be noted that participants never received any feedback during evaluations with the MPT and therefore one can conclude that the observed effects are caused by the acclimatization to the NFC technology rather than by repeated exposure to the test material.

This study further found that the extended use of NFC become helpful after lengthy acclimatization in better understanding speech in noise. This is in contradiction with another study where it was found that NFC does not improve sentence recognition in noise and that there is no significant correlation between the NFC benefit and period of acclimatization [5]. The study by Wolfe and colleagues [8] did however find that the benefit from NFC (both for consonant recognition and sentence intelligibility in noise) was greater following six months after the initial fit. It should be noted that the study by [5] included adult participants with a mean age of 75 years whereas the participants in the current study is much younger (aged 20 to 69 years) and that the study by Wolfe et al. [8] included children compared to adults in the current study. Clearly, this continues to be an area of interest and future research should focus hereon to establish the clinical significance of the benefit of NFC in noise and with extended use.

If a larger sample were made available the statistical power could be increased and stronger assumptions about the impact of extended use and NFC could be made. Until this is possible, it is interesting to note that NFC shows a benefit on two of four sub scales of the MPT even when initially fit. Assumptions that NFC distorts sound and requires a learning phase before it is useful are therefore contradicted. The implementation appears, in severe to profound listeners, to improve information that is useful during the MPT and this information is available immediately. Additional testing of this hypothesis is underway to better understand what is useful, and whether this will generalize to milder hearing losses.

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