Effect of Hearing Aid Acclimatization on Auditory and Working Memory Skills in Individuals with Hearing Impairment

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14AUD003

This Dissertation is submitted as part fullfillment for the Degree of Master of Science in Audiology University of Mysuru, Mysuru

All India Institute of Speech and Hearing Manasagangothri Mysuru-570006

May, 2016

Certificate

This is to certify that this dissertation entitled **"Effect of hearing aid acclimatization on auditory and working memory skills in individuals with hearing impairment"** is a bonafide work in part fulfillment for the Degree of Master of Science (Audiology) of the student (Registration No.14AUD003). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

May, 2016

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Director

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Declaration

This dissertation entitled **"Effect of hearing aid acclimatization on auditory and working memory skills in individuals with hearing impairment"** is the result of my own study under the guidance of Dr. Ajith Kumar, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier in any other University for the award of any Diploma or Degree.

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"Feeling gratitude, and not expressing it, is like wrapping a present and not giving it." –William Arthur Ward

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Abstract

Improvement in hearing and related domains following hearing aid use is termed as hearing aid acclimatization. Hearing aid acclimatization is observed in auditory and speech perception skills. However, it is not known if there is a transfer of acclimatization affects to other domains such as working memory skills. This study aimed to investigate the effect of hearing aid acclimatization on some auditory and working memory skills in individuals with mild to moderate cochlear hearing loss. For this purpose, working memory and auditory assessments were carried out on 10 individuals with cochlear hearing loss, immediately after the fitment of hearing aid and after one month of hearing aid use. Working memory assessment included reading span, auditory digit span and auditory sequencing and auditory assessment included gap detection thresholds, temporal modulation transfer function, pitch discrimination thresholds, duration pattern thresholds, concurrent vowel identification and speech perception in noise. Results revealed that hearing aid use for one month did not bring significant acclimatization effect on working memory skills and most of the auditory skills. However, speech perception in noise showed significant improvement following one month of hearing aid use.

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Chapter 1 – Introduction

Hearing aids amplifies the sound in order to compensate for the hearing loss that a hearing impaired individual experience. The amplification will increase the audibility and hence enhance the speech cues that were inaudible previously. On using the hearing aid the hearing aid user might experience an immediate improvement in understanding speech. This improvement might increase over time as the hearing aid user gets accustomed to the hearing aid. This improvement can be an effect of practice or a form of perceptual learning. This affect is known as "auditory acclimatization"(Arlinger et al., 1996). The acclimatization effect seems to be greatest in difficult listening situations (nonsense syllable recognition in noise) (Ellis & Munro, 2015). The perceptual consequences of hearing aid fitting in sensorineural hearing loss listeners also support auditory acclimatization effect (Philibert, Collet, Vesson, & Veuillet, 2005).

Hearing aid acclimatization results in improvements in hearing and other related areas. Previous research has indicated improvement in the speech discrimination over time (Bentler, Niebuhr, Getta, & Anderson, 1993; Gatehouse, 1992). Once the hearing aid user gets adapted to the amplification the benefits are seen in multiple facets. The benefits are not restricted only to the speech recognition abilities but also involves other aspects of communication and his/her satisfaction as a hearing aid user (Humes, Wilson, Barlow, Garner, & Amos, 2002). Hearing aid acclimatization also results in increased subjective benefit and sound quality (Bentler et al., 1993; Ovegård et al., 1997), loudness perception and intensity discrimination (Philibert, Collet, Vesson, & Veuillet, 2002), temporal spatial aspects (Dawes, Munro, Kalluri, & Edwards, 2013) and cognitive aspects (Choi et al., 2011; Pichora-Fuller &

Singh, 2006; Pinheiro, Iório, Miranda, Dias, & Pereira, 2012). The above studies mostly reported a small but a significant effect of acclimatization while there are few studies reporting of no significant difference between the experienced and the new hearing aid users (Smeds et al., 2006a, 2006b).

The benefit of hearing aid is seen in different areas including social, emotional, cognition and communication, though the changes in cognition are reported to be minimal (Mulrow, Tuley, & Aguilar, 1992). Working memory is a system for the temporary storage, management and manipulation of information required for carrying out complex cognitive tasks such as language comprehension" (Daneman & Carpenter, 1980). As age advances, the auditory performance declines significantly over a period of time. The decline usually is manifested in pure tone thresholds as well as in all speech understanding measures suggesting that nature of speech perception changes in accordance with age. Auditory thresholds measures the speech perception by the peripheral auditory system while the effect of age depicts the degradation of central structures which are accountable for low rate temporal processing (Divenyi, Stark, & Haupt, 2005). The age related decline seen in physiological integrity of neural subsystems is common for sensory as well as cognitive processing and hence it is found that both sensory and cognitive aging would occur concurrently (Lindenberger & Baltes, 1994). Sensory deprivation due to hearing loss contributes to decline in cognitive function (Uhlmann, Larson, Rees, Koepsell, & Duckert, 1989). Peelle, Troiani, Grossman and Wingfield, (2011) supported this with an fMRI study which unveiled the relationship between speech abilities and the cortical structures.

Hearing aids now have more complex operations and hence emulate different aspects like higher- level auditory function and cognitive processing which involves attention, memory and language (Pichora-Fuller & Singh, 2006). Choi et al., (2011) reported of improved speech related cognitive function of hearing impaired individuals post hearing aid use indicating hearing aid induce acclimatization of central auditory system. Hearing aids if worn at the early stages of hearing loss it improves the individuals performance on auditory working memory tests (Doherty & Desjardins, 2015).

Need for the study

From the literature mentioned above, it is clear that there is deterioration in the hearing, auditory processing, speech processing and working memory capacity due to aging. It is been observed that auditory and speech perception skills improve with the fitment of the hearing aid over time. This improvement is termed as hearing aid acclimatization. However, it is unclear whether there general transfer of acclimatization affects to other domains such as working memory skills. Given a strong relationship between auditory, speech perception and working memory skills, we hypothesise that hearing fitment may improve persons WMC over time and may result in cognitive acclimatization.

Aim of the study

The present study aims to investigate the effect of hearing aid acclimatization on auditory and working memory skills in individuals with hearing impairment.

Objectives of the study

- ✓ To measure and compare gap detection thresholds, temporal modulation transfer function, pitch discrimination thresholds, duration pattern thresholds, concurrent vowel identification and speech perception in noise on first fit and after one month of hearing aid use.
- ✓ To measure compare reading span, auditory digit span and auditory sequencing on first fit and after one month of hearing aid use.

Chapter 2 - Review of literature

Acclimatization is the process in which an individual organism adjusts to a gradual change in its environment allowing it to maintain performance across a range of environmental conditions (Gatten, Echternautch, & Wilson, 1988). Many clinicians are concerned with the time and benefits of hearing aid amplification and acclimatization. A hearing aid user should wait in order to make sure of the benefit being provided by an amplification device in everyday listening situations, though the answer remains unclear. Taylor, (2007) reviewed literature on acclimatization and concluded - " the average length of time a patient may require to become accustomed to their hearing aids, regardless of user history, is approximately 30 days". Literature on hearing aid acclimatization is inconclusive. Several studies reveals that there was very little evidence to support acclimatization of hearing aid benefit (Humes, Wilson, Barlow, & Garner, 2002; Saunders & Cienkowski, 1997). Dawes et al., (2013) revealed a large test-retest variability that overshadowed small average acclimatization effects and also found that improvement was associated not with the hearing aid use but with better cognitive ability and younger age.

Acclimatization of auditory behavior

Bender, Getta, & Anderson, (2015) studied 65 individuals for 12 months post hearing aid fitting. Objective test were performed which included insertion gain, speech perception in noise and nonsense syllable test. The results revealed little change in performance over 12 months. There was a consistent performance on speech recognition task and few showed improvement in speech recognition performance. Gatehouse, (1992) investigated 4 subjects having bilateral symmetrical sensorineural hearing loss using single hearing aid. The headphone stimulation was used to assess the speech identification scores. The speech identification abilities significantly increased in the aided ear also there was a decrease in the speech identification scores of unaided ear. Hence, this study supports the existence of perceptual acclimatization which occurs over a period of 6 to 12 weeks. Philibert et al., (2002) compared intensity – related performance between two groups with sensorineural hearing impairment. The two groups comprised of long term hearing aid users and non hearing aid users. The tests performed were discrimination limen for intensity task and loudness scaling task. The results revealed a significant difference in loudness perception in long term hearing aid users when compared non hearing aid users. Choi et al., (2011) investigated speech related cognitive function and speech recognition ability in hearing impaired individuals using hearing aids. The findings revealed a significant improvement in both speech in noise and working memory skills following hearing aid use indicating acclimatization of central auditory system. Pinheiro et al.,(2012) studied speech recognition processes in 60 elderly individuals. The tests performed were percentage index of speech recognition test, dichotic digit test before and after hearing aid use. Results revealed an improvement in the speech recognition scores followed by the hearing aid use and also they found that subjects having cognitive problem performed poorer in both tests that was administered.

Cox & Alexander(1992) reported that there is an improvement during the first 10 weeks of hearing aid use. They also reported that initial benefit in noisy/ reverberant situations gives a good estimate of long term benefit in similar situations. Gatehouse(1993) reported of an improved aided speech understanding over 16 weeks in experienced hearing aid users. Horwitz & Turner (1997) did a study on 13 experienced and 13 new hearing aid users and found that there was a significant change in the objective tests only in new hearing aid users. Kuk, et al. (2003) and

Yund, Roup, Simon and Bowman, (2006) found that the improvement is even seen in experienced hearing aid users when they shift to WDRC hearing aids from linear hearing aids.

Acclimatization as measured by benefit questionnaire

Bentler et al., (1993) did a longitudinal follow up of hearing aid users for around 12 months. Subjective tests were performed which included hearing performance inventory (HPI), expectation checklist, qualitative judgement task and a satisfaction questionnaire. Results revealed that only understanding speech in a fairly quiet background subscale of HPI showed significant change. Satisfaction ratings remained constant from 6 to 12 months and expectations checklist did not provide the anticipated insight into self- perceived benefit. Humes et al.,(2002) reported results from 134 hearing aid user regarding the hearing aid benefit measures during 1st year of hearing aid use. The measures were taken at 1 month, 6 month and 1 year of hearing aid use. Subjective self reports like hearing aid performance inventory (HAPI) and hearing handicap inventory for elderly (HHIE) were performed. Results revealed that performance was significantly worse at 6 month and 1 year when compared to 1 month post fit benefits. Munro & Lutman, (2005) reported a small but statistically significant improvement in self-report outcome in one group, while in another group, using a different version of the same questionnaire (GHABP), no such improvement was observed suggesting self-reporting is unfit for measuring changes in auditory performance over time as the result will depend on the type of questionnaire used. Kuk et al.,(2003) reported of postponing the initial self- report outcome assessment by at least one month as self-reporting without any experience would arguably be meaningless. However they failed to show an evidence of acclimatization in the self report domain, and hence concluded that future studies should examine self-report benefit and satisfaction closer to the initial fitting.

Malinoff & Weinstein, (1989) studied 25 individuals using linear hearing aids and concluded that there was a large improvement in benefit after 3 weeks, gradually decreased thereafter. Similar findings were reported by Amorim & Almeida, (2007). Vestergaard, (2006) reported a change in subjective measures but no change was reported in objective measures. Studies also have reported of no significant benefit up to 3 months to 2 years in hearing aid benefit (Humes, Wilson, Barlow, Garner & Amos , 2002; R.K., M.T., & B.E., 1998; Saunders, Gabrielle H.; Cienkowski, 1997).

Working memory capacity (WMC) and cognition

The prediction of performance on a wide range of real-world cognitive tasks is done by different measures of WMC. Working memory storage capacity is important as it completes cognitive task only with sufficient ability to hold information as it is processed and the ability to hence repeat information depends on task demands and it can be distinguished from a more constant, underlying mechanism: a central memory store which is limited to 3 to 5 meaningful items in young adults. WMC is treated as a unitary construct which explains an individual's cognitive mechanism like storage and attention control. It is found that maintenance/disengagement in primary memory, retrieval from secondary memory and attention control mechanisms is important to explain individual differences with respect to working memory capacity. The type of task used to operationalize WMC shows us how apparently it can be driven. Specifically, complex span includes processing and storage; visual arrays which includes change detection. The performance in this is strongly related to a person's attention control, while the running memory span performance has a relationship to primary memory.

Several studies have, however, demonstrated that multiple mechanisms are needed to explain individual differences in working memory capacity. Primary memory, secondary memory, and attention control are all critical components of WMC and these mechanisms are not similarly represented by all working memory tasks thus running memory span performance reflects primary memory more strongly than either complex span or visual arrays tasks (Shipstead, Lindsey, Marshall, & Engle, 2014). Complex-span tasks, updating tasks, and binding tasks all shared a large proportion of variance, which reflects a broad general WMC construct (Wilhelm, Hildebrandt, Oberauer, & Conway, 2013).

It is found that cognitive abilities such as WMC decrease with age (Salthouse, 2010). Studies have shown neurophysiologic correlates of age-related reduction in working memory capacity. At higher working memory loads, there is reduced activity in older population in the prefrontal regions suggesting that, within capacity, compensatory mechanisms activity are called upon in order to maintain proficiency in task performance, as the cognitive demand increases, physiological compensation cannot be made and, leads to a decline in the performance (Mattay et al., 2006).

When considering the auditory and the cognitive ability of a person it is seen working memory and visuospatial abilities showed the strongest interrelationship to spectral-pattern discrimination performance (Sheft, Shafiro, Wang, Barnes, & Shah, 2015). It is also found that High-WMC individuals were more sensitive than low-WMC at discriminating the longer of two temporal intervals across a range of temporal differences (Broadway & Engle, 2011). This gives us a conclusion that auditory training can improve the working memory capacity. A generalized improvement was seen in the measures of self reported hearing, competing speech, and complex cognitive tasks as a result of auditory training suggesting that development of cognitive development to be more important than the refinement of sensory processing. Hence concluding a combined auditory-cognitive training approaches for adults with hearing loss (Ferguson & Henshaw, 2015). WMC which is important for speech understanding especially in noisy situations is negatively affected by the hearing loss. The hearing loss being untreated would interfere with the cognitive abilities and intellectual function of an individual. Studies have revealed that hearing aids worn during the early stages of an age-related hearing loss is likely to improve a person's performance on auditory working memory tests (Doherty & Desjardins, 2015).

Lunner, (2003) conducted 2 experiments investigating relationship between cognitive function and hearing aid use. The tests performed included speech recognition in noise with and without hearing aids. Cognitive function was assessed by using working memory test that is reading span test and verbal information-processing speed. The results revealed that, significant correlations between the measures of cognitive performance and speech recognition in noise, in both conditions. Experiment 2, had first time hearing aid user with either high or low working-memory capacity .The results revealed that those with high working-memory capacity were better than those compared with low capacity. Rudner, Foo, Ronnberg, & Lunner, (2009) tested speech recognition under different conditions and concluded that cognitive measures were not the main predictors of performance. Elaine et al., (2014) reported of a significant correlation between reading span and speech reception threshold during the hearing aid fitting session however this relation was significantly weakened over the first 6 months of hearing aid use. Akeroyd, (2008) surveyed 20 experimental studies and have reported of mixed results about the cognition being a useful predictor of hearing aid benefit.

Since the literature has shown a controversial finding regarding the hearing aid acclimatization and its effects on the working memory capacity and auditory skills. Thus there is a need to study and elucidate the effects of hearing aid acclimatization on WMC and auditory skills.

Chapter 3 – Method

Participants

Fourteen adults in the age range of 50 to 65 years participated in the study. All participants had bilateral mild to moderate acquired cochlear hearing loss . All the participants were native speakers of Kannada and were able to read and write Kannada. None of the participants showed any evidence of middle ear pathology on immittance evaluation. All participants were naive users of hearing aids. A structured interview was carried out to rule out any gross neurological, cognitive or otological problems. Of the 14 participants only 10 completed the study and hence data from only 10 participants was analyzed. Written informed consent was obtained from all participants prior to their participation.

Hearing aid fitment

All participants were naive hearing aid users. Bilateral digital hearing aid was fitted to all participants using the clinical protocol followed at Department of Audiology, All India Institute of Speech and Hearing. In brief, this involved hearing aid programming and fine tuning using speech identification measures. Paired comparisons between the hearing aids were used for selecting the desired hearing aid.

Test environment

All audiological assessments were carried out in a sound treated room with ambient noise levels within the permissible limits as per ANSI (ANSI S3.1- 1999). Other auditory and cognitive tests were carried out in a quiet room with minimal visual distractions

Procedure

After routine audiological evaluation and hearing aid fitment participants underwent detailed working memory and auditory assessment. Working memory and auditory assessments were done twice - immediately after the fitment of hearing aid and after one month of hearing aid usage. All audiological evaluations and structured interview was repeated before the second assessment also.

Working memory assessment

The cognitive assessment included primarily assessment of working memory - reading span task, auditory digit span and auditory sequencing.

Reading span task

In reading span task, participants' ability to remember the target stimuli which interleaves with a secondary processing task was evaluated. The secondary processing task was verifying semantic/pragmatic correctness of a sentence. Stimulus for the reading span task had been developed following the guidelines of Kane et al. (Kane et al., 2004). The test was administered using paradigm player. It consisted of a sentence and a syllable to be remembered (e.g. "Ramu is going to school. /ka/").Each element was defined as a combination of one sentence and a syllable to be remembered. Half of the sentences were logical (e.g. Apples are falling from an Apple tree) and other half of the sentences did not follow logic (e.g. People are falling sick because of increasing flowers). The syllables to be remembered were in CV structure with combination of different consonants and vowels. Combinations of a number of elements were defined as a trial. Each trial consisted of two to five elements (sentence-syllable combinations). Three trials of each length were presented for a total of 12 trials (4 lengths × 3 trials).

During testing, an element that is a sentence was displayed on the computer screen followed by a syllable to be remembered. The participant's task was to read the sentence aloud and indicate whether it made sense and then read the syllable. Soon after, next sentence-syllable combination was presented. After all the elements in a trial were presented, the participant had to recall each syllable from the preceding set of sentences, in the order they appeared. The number of elements in each trial was varied randomly so that the difficulty level would not be predicted at the beginning of the trial. The accuracy of judging the sentence and also recalling the syllables in the same order was noted.

Scoring was done according to the guidelines provided by Kane et al. (Kane et al., 2004) and Conway et al. (Conway et al., 2005). One point was provided for each element recalled in the correct serial order irrespective of the error made in verifying the processing component of the task (judging whether the sentence made sense). However, it was ascertained that the accuracy on the processing component of the task was not less than 80%. Further, proportion correct score for each trial was calculated and averaged across all the 12 trials to obtain the final score which was the reading span of the participant.

Auditory sequencing

Auditory number sequencing included ascending and descending span. In auditory number sequencing a cluster of numbers were presented increasing in length. The participants’ task was to arrange the number in lowest to highest order in ascending span and vice versa in descending span. Total score was calculated based on the digits the participant can successfully recall.

Auditory digit span

Auditory digit span was divided into forward and backward phase. Cluster of digits were presented in random order. The participant's task was to reproduce them in the same order in forward phase and backward order in backward phase. Total score was calculated based on the digits the participant could successfully recall.

Temporal and speech perception assessment

All temporal processing tests except for the duration pattern test were carried out using 'mlp' procedure (Green, 1990) implemented in Matlab. Details of the stimuli and procedure can be found in Grassi & Soranzo (2008).

Temporal processing

The temporal processing tests included Gap Detection Test (GDT), Duration Pattern Test (DPT), Temporal Modulation Temporal Function (TMTF) and Pitch Discrimination Test (PDT). Stimuli were played at 44,100 Hz sampling rate. Two interval alternate forced choice method was used to estimate the threshold. Stimuli were presented binaurally at an intensity of 80 dB SPL through EAR-3A earphones via laptop.

Gap detection test (GDT): The participant's task was to detect a temporal gap in the centre of a 750 ms broadband noise. The standard stimulus was 750 ms broadband noise with no gap whereas the variable stimuli contained a gap.

Duration pattern test (DPT): The participant's task was to sequence 1000 Hz pure tone of two different durations. The duration of the short stimuli was 250ms and long stimuli was 500 ms with an inter stimulus interval of 250 msec. Six different patterns were generated using the two stimulus. Participants were asked to repeat the sequence verbally.

Pitch discrimination test (PDT): Pitch discrimination threshold was found for a 250 ms complex tone. The tone had four harmonics. The subject had to detect the highest pitch tone. Onset and offset of tones were gated on and off with two 10 – ms raised cosine ramps.

Temporal Modulation Temporal Function (TMTF): Temporal modulation refers to a reoccurring change in a signal over time. A 500msec sinusoidal amplitude modulated noise at modulation frequencies of 2Hz, 4Hz, 8Hz, 16Hz, 32Hz, 64Hz, 128Hz, 256Hz were included. The participant's task was to detect the modulation and determine which interval had modulated noise. Depth of the modulated signal was varied based on the participant's response.

Concurrent vowel identification (CCV)

Stimuli used for concurrent vowel identification was same as that reported in (Kumar, Nambi & HR, 2015). Briefly, five vowels /a/, /e/, /i/, /o/, /u/ was synthesized at the sampling rate of 20 kHz with 270 ms duration using Klatt synthesizer. All the vowels were scaled to have same amplitude. The vowels were synthesized with two fundamental frequencies - 120 Hz and 220 Hz. Later the these vowels were resynthesized with 1, 2 and 4 semitones increase from base fundamental frequency resulting in 20 vowels for each base f0 condition. For the purpose of concurrent vowel identification, the vowels were paired with each other. Same vowels were not paired even though they had different F0. Vowel /a/ was kept constant and other vowels were variable which were considered as target stimuli. Vowels within the pair were presented simultaneously to one ear at a time. The task of the particpant was to identify the vowel ignoring the competent vowel while presented simultaneously to one ear at a time. All 5 vowels were appearing on the screen and the participant had to click on the respective vowel button. Feedback was given for every correct answer.

Speech perception in noise measurement

Speech perception in noise was assessed using Quick speech in noise developed by (Methi, Avinash & Kumar 2009). The test included presentation of sentences without hearing aids with different SNR levels. The presentation was through headphones at comfortable level.

Chapter 4 – Results and Discussion

The aim of the present study was to check for the hearing aid acclimatization on some auditory and cognitive measures following one month of hearing aid use. For this purpose reading span task, auditory digit span, auditory sequencing and gap detection thresholds, temporal modulation transfer function, pitch discrimination scores, duration pattern scores, concurrent vowel identification, speech perception in noise was assessed at the initial fit of hearing aid and after 1 month of hearing aid use. Initially 15 individuals were recruited for the study. However, only 10 participants came back for the second evaluation. Therefore, results of only 10 participants are reported. The analysis was done using IBM SPSS 20.0 software package. Normality of the data was tested using Shapiro-Wilk normality test. Since, most of the data was non-normally distributed non-parametric tests were used for analysis.

Working memory assessment

Reading span

Table 1 shows median, mean, range and one standard deviation of reading span scores between two evaluations. Figure 1 show reading span scores of individual participants across two evaluations. Figure 1 and Table 1 reveals that reading span scores did not change much following one month hearing aid use. Maximum change in the reading span score was 2.2 in participant 10. Wilcoxon sign-rank test revealed no significant difference between the reading span scores measured across two evaluations ($|z|=1.581$, $p>0.05$).

Table 1

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for reading span

	Mean	Median	Range	Std. Deviation
Reading span score evaluation 1	3.00	2.95	1.35-5.55	1.20
Reading span score evaluation 2	3.01	2.95	1.60-4.70	1.09

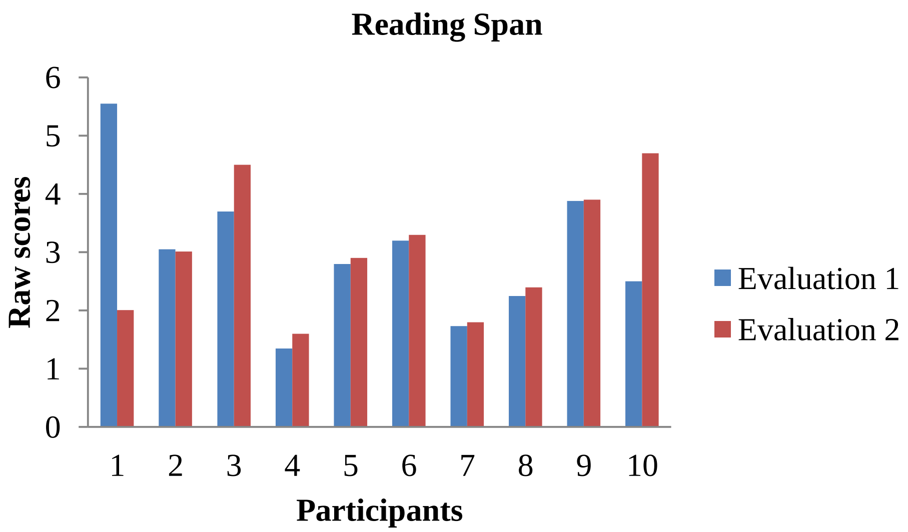

Figure 1: Raw scores for evaluation 1 and evaluation 2 for reading span. The x-axis represents participants and y-axis represents raw scores

Auditory sequencing

This section of testing involved ascending span and descending span. Table 2 and Table 3 shows median, mean, range and one standard deviation of ascending span scores and descending span scores respectively between two evaluations. Figure 2 and Figure 3 shows ascending span scores and descending span scores of individual participants respectively across two evaluations. Figure 2 and Table 2 reveals that ascending span scores did not change much following one month hearing aid use. Maximum change in the ascending span score was 1 in participant 3, 6 and 9. Wilcoxon sign-rank test revealed no significant difference between the ascending span scores measured across two evaluations ($|z|=1.732$, $p>0.05$). Similar findings were found for descending span also. Maximum change in the descending span score was 1 in participant 3, 6 and 9. Wilcoxon sign-rank test revealed no significant difference between the descending span scores measured across two evaluations ($|z|=1.000$, $p>0.05$).

Table 2

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for ascending span

	Mean	**Median**	**Range**	**Std. Deviation**
Ascending span evaluation 1	4.40	4.50	2.00-7.00	1.50
Ascending span evaluation 2	4.10	4.00	2.00-6.00	1.19

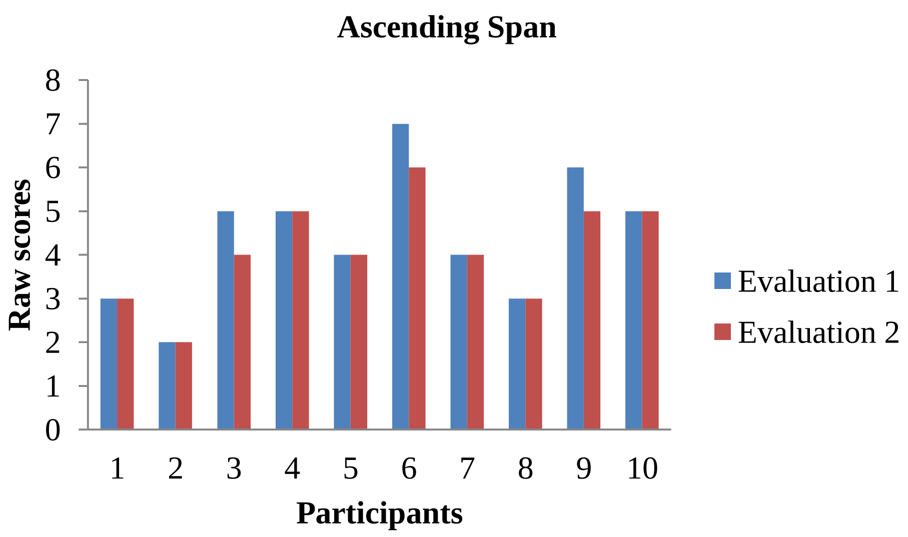

Figure 2: Raw scores for evaluation 1 and evaluation 2 for ascending span. The x-axis represents participants and y-axis represents raw scores

Table 3

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for descending span

	Mean	**Median**	**Range**	**Std. Deviation**
Descending span evaluation 1	3.90	4.00	2.00-6.00	1.44
Descending span evaluation 2	4.00	4.00	2.00-6.00	1.33

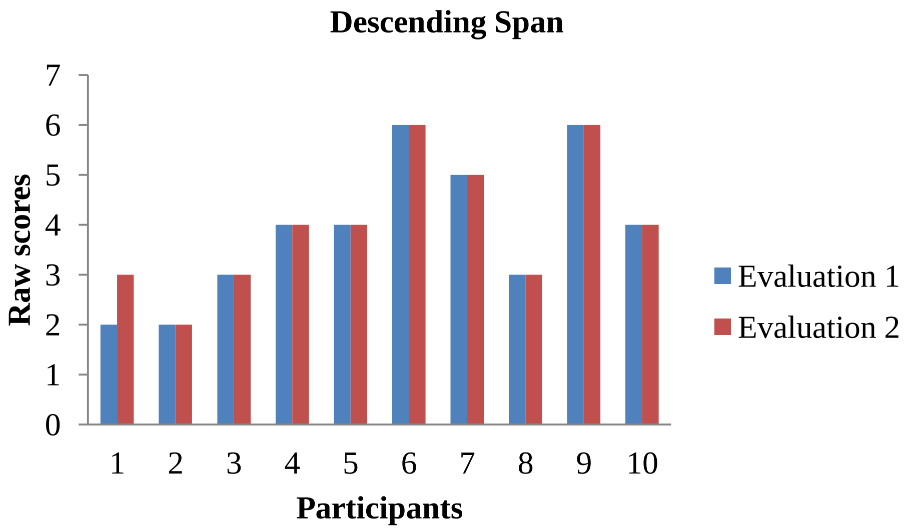

Figure 3: Raw scores for evaluation 1 and evaluation 2 for descending span. The x-axis represents participants and y-axis represents raw scores

Auditory digit span

Auditory digit span was divided into forward and backward phase. Table 4 and Table 5 shows median, mean, range and one standard deviation for forward and backward digit span scores between two evaluations. Figure 4 and Figure 5 shows forward and backward digit scores of individual participants across two evaluations. Figure 4 and Table 4 reveals that forward digit scores did not change much following the one month hearing aid use. Maximum change in the forward digit score was 1 in participant 2 and 6. Wilcoxon sign-rank test revealed no significant difference between the forward digit scores measured across two evaluations ($|z|=0.000$, $p>0.05$). Similar findings were found for backward digit span ($|z|=1.414$, $p>0.05$). Maximum change in the backward digit score was 1 in participant 1 and 2.

Table 4

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for forward digit

	Mean	Median	Range	Std. Deviation
Forward digit evaluation 1	4.50	4.00	2.00-7.00	1.17
Forward digit evaluation 2	4.50	4.00	3.00-6.00	0.97

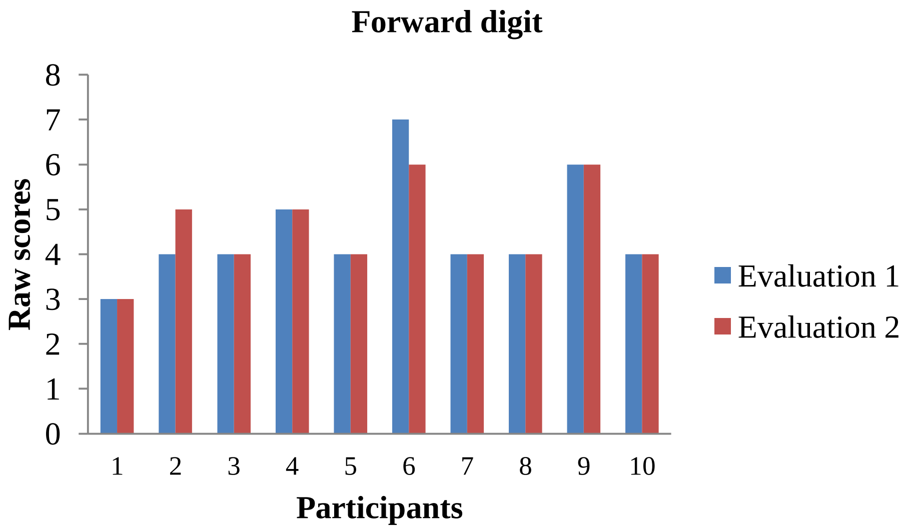

Figure 4: Raw scores for evaluation 1 and evaluation 2 for forward digit. The x-axis represents participants and y-axis represents raw scores

Table 5

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for backward digit

	Mean	Median	Range	Std. Deviation
Backward digit evaluation 1	3.60	3.00	2.00-6.00	1.31
Backward digit evaluation 2	3.80	3.50	2.00-6.00	1.31

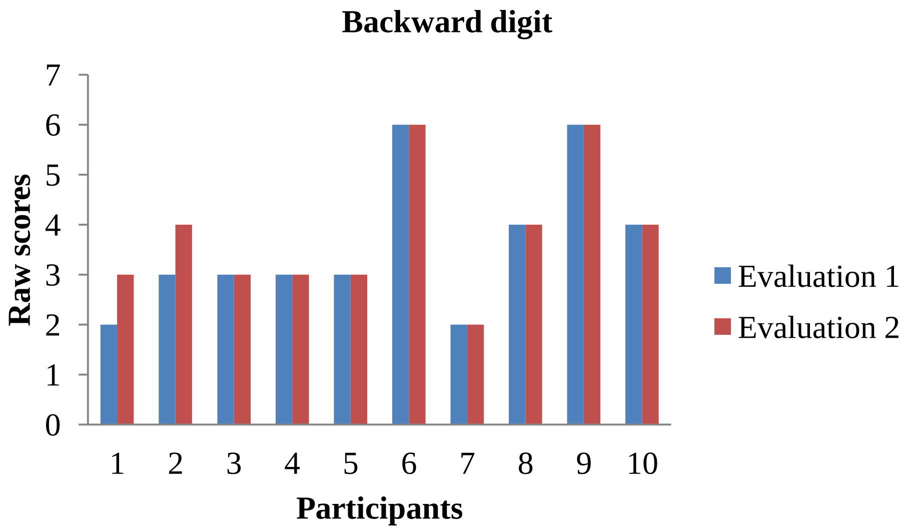

Figure 5: Raw scores for evaluation 1 and evaluation 2 for backward digit. The x-axis represents different participants and y-axis represents raw scores

Temporal and speech perception assessment

Temporal processing

This included gap detection test (GDT), duration pattern test (DPT), pitch discrimination test (PDT) and temporal modulation transfer function (TMTF).

GDT, DPT and PDT

Table 6, Table 7 and Table 8 shows median, mean, range and one standard deviation of GDT, DPT and PDT scores respectively between two evaluations. Figure 6, Figure 7 and Figure 8 shows GDT, DPT and PDT scores of individual participants respectively across two evaluations. Figure 6 and Table 6 reveals that GDT scores did not change much following the one month hearing aid use. Maximum change in the GDT score was 3.7 ms in participant 10. In 5 participants improvement was less than 1ms. Wilcoxon sign-rank test revealed no significant difference between the GDT scores measured across two evaluations ($|z| = 1.785$, $p>0.05$). Similar findings were found for DPT ($|z| = 0.141$, $p>0.05$) and PDT ($|z| = 0.255$, $p>0.05$).

Table 6

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for GDT in ms

	Mean	**Median**	**Range**	**Std. Deviation**
GDT evaluation 1	7.88	8.16	5.00-11.50	1.92
GDT evaluation 2	6.71	6.25	3.67-10.33	2.22

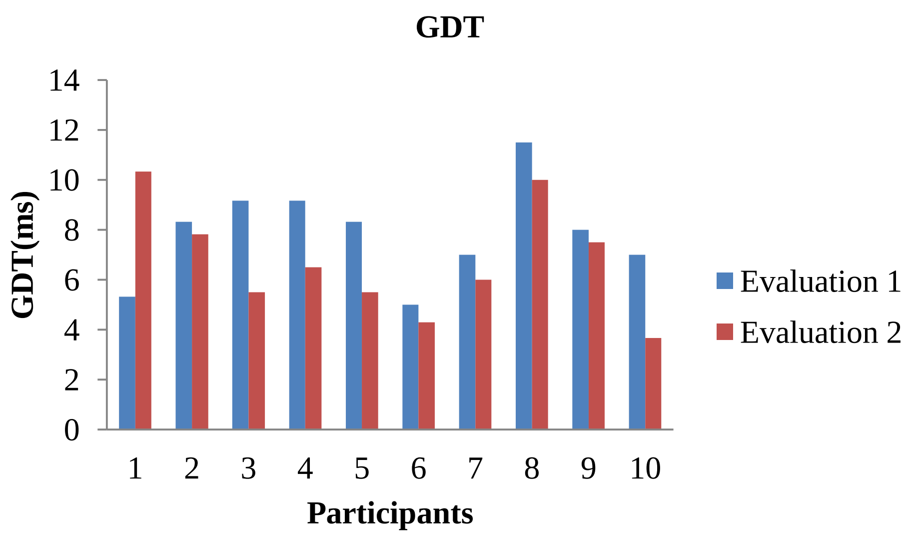

Figure 6: Gap detection thresholds for evaluation 1 and evaluation 2. The x-axis represents participants and y-axis represents GDT in ms

Table 7

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for DPT

	Mean	Median	Range	Std. Deviation
DPT evaluation 1	24.10	24.00	18.00-29.00	3.78
DPT evaluation 2	23.80	24.00	18.00-28.00	4.18

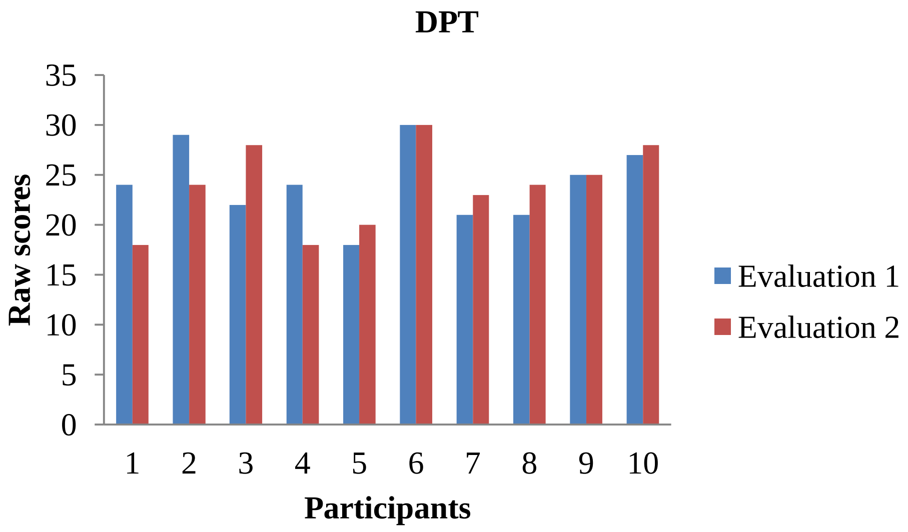

Figure 7: Raw scores for evaluation 1 and evaluation 2 for DPT. The x-axis represents participants and y-axis represents raw scores

Table 8

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for PDT in Hz

	Mean	**Median**	**Range**	**Std. Deviation**
PDT pre	19.44	17.31	6.50-50.00	12.45
PDT post	20.28	16.41	5.33-64.83	17.87

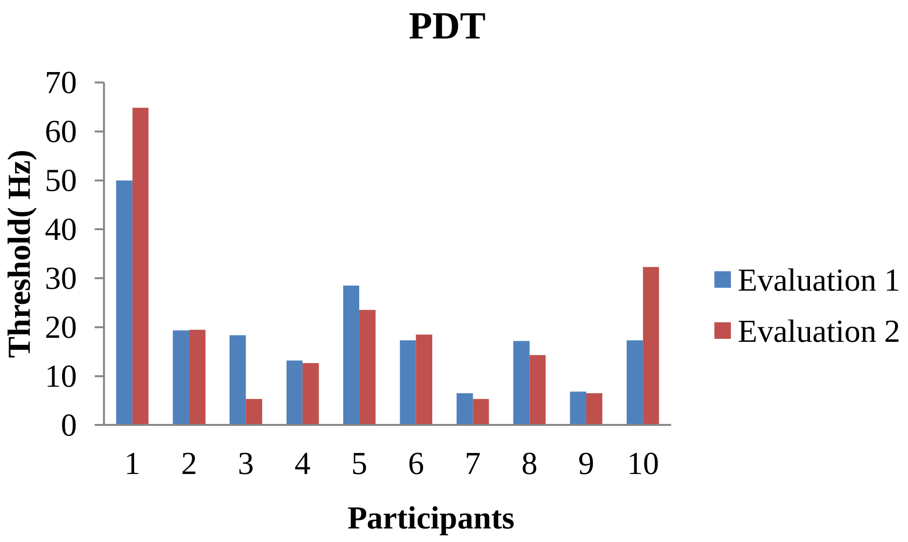

Figure 8: Thresholds for evaluation 1 and evaluation 2 for PDT. The x-axis represents participants and y-axis represents thresholds in Hz

Temporal modulation transfer function

Modulation detection thresholds were measured at different modulation frequencies. The modulation frequencies included were 2Hz, 4Hz, 8Hz, 16Hz, 32Hz, 64Hz, 128Hz and 256Hz. Table 9 shows median, mean, range and one standard deviation of modulation delectation thresholds for different modulation frequency between two evaluations. Figure 9a and 9b shows TMTF of individual participants across two evaluations. Table 10 gives z values and significance levels between two evaluations across different modulation frequencies. From the table it can be seen that modulation detection thresholds increased significantly following one month of hearing aid use only for 32 Hz modulation frequency.

Table 9

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for TMTF at different modulation frequency in dB

		Mean	**Median**	**Range**	**Std. Deviation**
TMTF 2 Hz	Evaluation 1	-16.69	-19.41	(-21.67) - (-4.33)	5.41
	Evaluation 2	-17.96	-18.50	(-23.00) - (13.00)	3.60
TMTF 4 Hz	Evaluation 1	-22.93	-24.16	(-26.17)- (-12.00)	4.94
	Evaluation 2	-23.26	-24.08	(-29.17)- (-12.00)	4.97
TMTF 8 Hz	Evaluation 1	-21.86	-23.33	(-24.50)- (-18.00)	2.58
	Evaluation 2	-23.05	-24.08	(-25.00)- (-18.17)	2.24
TMTF 16 Hz	Evaluation 1	-19.70	-19.16	(-26.00)- (-17.00)	2.57
	Evaluation 2	-20.51	-20.41	(-22.00)- (-18.50)	1.37
TMTF 32 Hz	Evaluation 1	-17.33	-17.00	(-21.50)- (-14.00)	2.70
	Evaluation 2	-19.04	-18.50	(-23.33)- (-15.00)	2.93
TMTF 64 Hz	Evaluation 1	-14.96	-14.33	(-20.67)- (-11.50)	2.72
	Evaluation 2	-15.53	-14.83	(-23.33)- (-9.61)	3.76
TMTF 126 Hz	Evaluation 1	-13.76	-13.24	(-15.83)- (-11.00)	2.11
	Evaluation 2	-14.13	-13.08	(-18.50)- (-11.67)	2.25
TMTF 256 Hz	Evaluation 1	-9.87	-9.00	(-14.16)- (-6.83)	2.70
	Evaluation 2	-8.62	-8.69	(-13.00)- (-8.00)	2.16

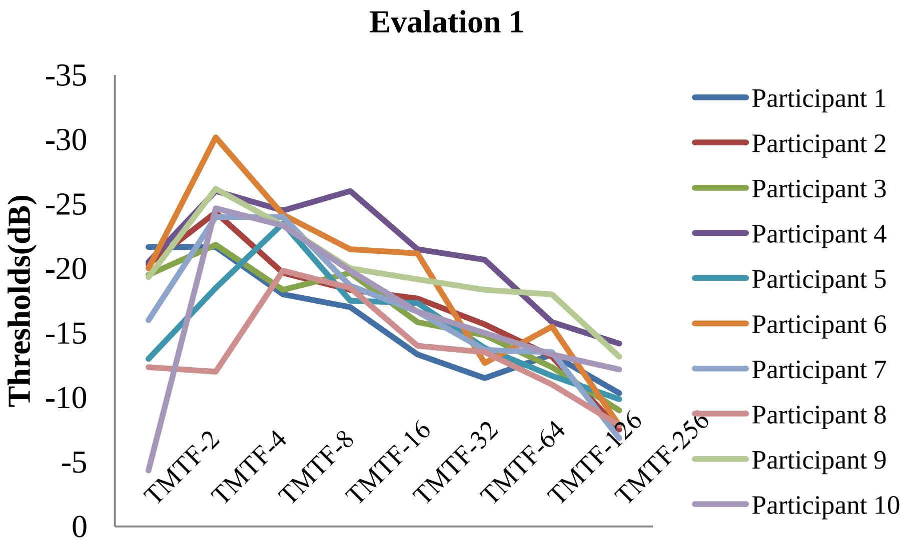

Figure 9.a

Modulation detection thresholds for TMTF at different modulation frequencies for evaluation 1. The x-axis represents modulation frequency and y-axis represents thresholds in dB

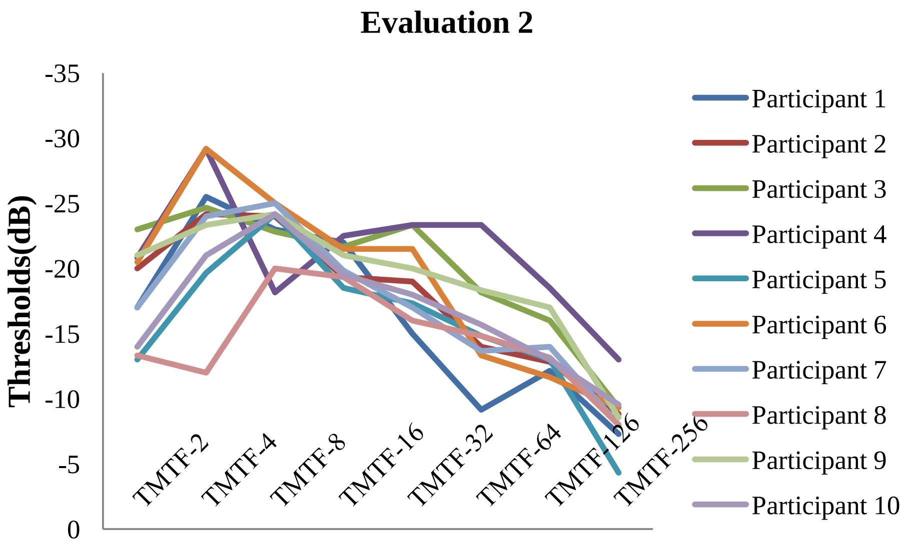

Figure 9.b

Modulation detection thresholds for TMTF at different modulation frequencies for evaluation 2. The x-axis represents modulation frequency and y-axis represents thresholds in dB

Table 10

The z values and significance levels assessed between two evaluations across different modulation frequencies

Modulation Frequencies	**z value**	**p value**
TMTF 2Hz evaluation 2 - TMTF 2Hz evaluation 1	1.543	0.123
TMTF 4 Hz evaluation 2 - TMTF 4 Hz evaluation 1	0.491	0.624
TMTF 8 Hz evaluation 2 - TMTF 8 Hz evaluation 1	1.785	0.074
TMTF 16 Hz evaluation 2 - TMTF 16 Hz evaluation 1	1.605	0.108
TMTF 32 Hz evaluation 2 - TMTF 32 Hz evaluation 1	2.670	0.008
TMTF 64 Hz evaluation 2 - TMTF 64 Hz evaluation 1	0.980	0.327
TMTF 126Hz evaluation 2 - TMTF 126Hz evaluation 1	0.561	0.575
TMTF 256Hz evaluation 2 - TMTF 256Hz evaluation 1	0.593	0.553

Concurrent vowel identification (CCV)

Table 11 shows median, mean, range and one standard deviation of CCV identification scores between two evaluations. Figure 10 shows CCV identification scores of individual participants across two evaluations. Figure 10 and Table 11 reveals that CCV identification did not change much following the one month hearing aid use. Maximum change in the CCV identification was 6 in participant 1. Wilcoxon sign-rank test revealed no significant difference between the CCV identification scores measured across two evaluations ($|z| = 0.783$, $p>0.05$).

Table 11

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for CCV

	Mean	Median	Range	Std. Deviation
CCV evaluation 1	8.00	8.50	4.00-10.00	2.00
CCV evaluation 2	8.50	9.00	5.00-10.00	1.77

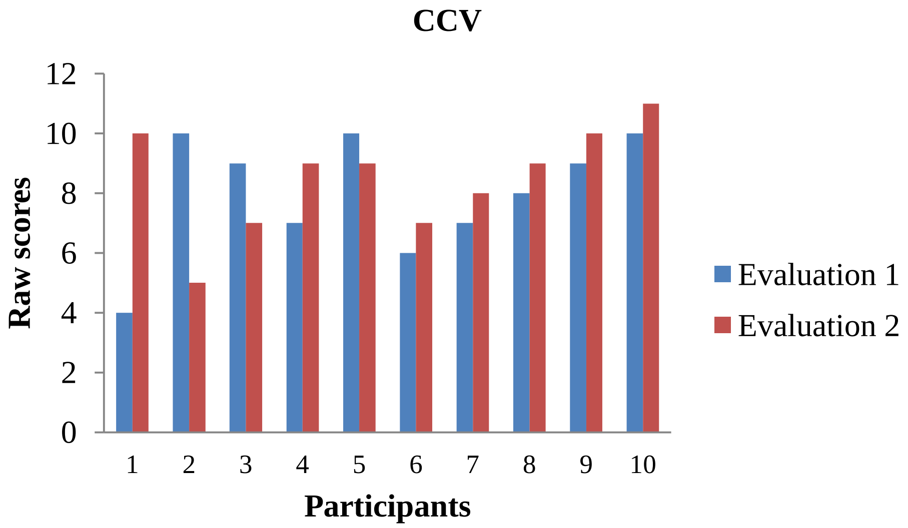

Figure 10: Raw scores for evaluation 1 and evaluation 2 for CCV identification. The x-axis represents participants and y-axis represents raw scores

Speech perception in noise measurements

Table 12 shows median, mean, range and one standard deviation of QuickSin scores (number of words identified) between two evaluations. Figure 11 shows QuickSin scores of individual participants across two evaluations. Figure 11 and Table 12 reveals that QuickSin scores improved following the one month hearing aid use. Wilcoxon sign-rank test revealed significant difference between the QuickSin scores measured across two evaluations ($|z|=2.419$, $p<0.05$). From the Figure 11 it can also be seen that participants who had 0 scores (word identification) on first evaluations achieved good speech perception abilities after one month use of hearing aid use.

Table 12

Mean, standard deviation, median and range values of evaluation 1 and evaluation 2 for QuickSin

	Mean	**Median**	**Range**	**Std. Deviation**
QuickSin evaluation 1	9.20	11.00	0.00-20.00	7.43
QuickSin evaluation 2	11.40	13.00	2.00-20.00	6.71

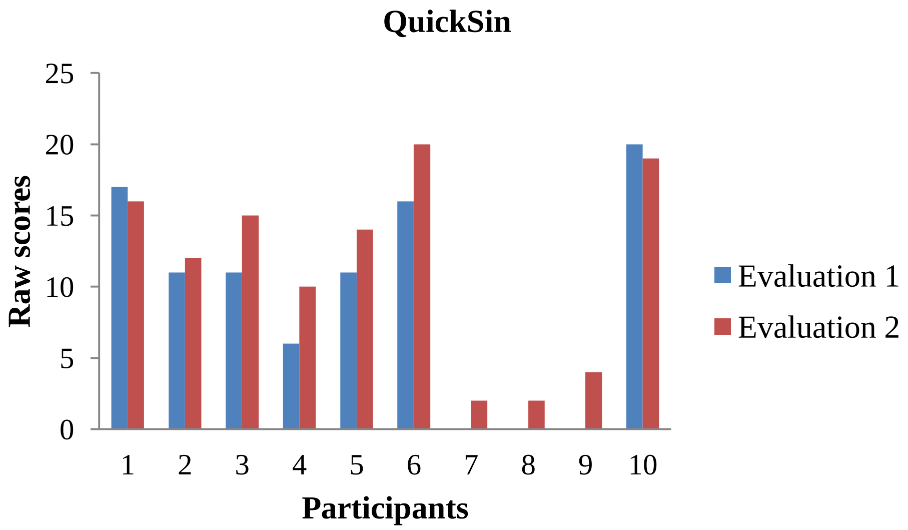

Figure 11: Raw scores for evaluation 1 and evaluation 2 for QuickSin. The x-axis represents participants and y-axis represents raw scores

In summary, one month use of hearing aid did not bring much change in all the working memory skills assessed. There was also no significant change in the majority of non-speech auditory tests. However, significant change was observed in speech perception in noise.

Main aim of the current study was to investigate the effect of hearing aid acclimatization on working memory and cognitive measures. Results showed that one month use of the hearing aids did not bring significant changes in any of the working memory skills assessed. Similar results are reported by other investigators too. Hooren et al., (2005) evaluated the effect of 12 months hearing aid use on cognitive functions in 56 older adults. They were compared with the age matched control group who were not fitted with hearing aids. Cognitive testing was assessed using stroop color word task, concept shifting task, letter digit substitution, visual verbal learning test and verbal fluency test. All the tests were administered on initial hearing aid fit and after 12 months. They found no significant improvement in cognitive test following 12 months of hearing aid use. They concluded that hearing aid use may alleviate the age related difficulties in hearing but has no significant effect on cognitive mechanisms mediated by central nervous system. Similar results were also reported by Tesch-Romer, (1997). He assessed hearing aid acclimatization following 6 months use of hearing aids. He examined the performance of hearing aid users on areas of communication problems, social activities, satisfaction, wellbeing and cognitive functioning. Results showed that hearing aid use had significant positive effect on self-perceived hearing handicap but did not change other domains including cognitive functioning. However, Choi et al.,(2011) reported positive effect of hearing aid use on cognitive functions. They assessed the visual verbal learning test on 18 hearing aid users following 6 months of hearing aid use and compared with control group who did not use hearing aids. Results showed visual verbal learning scores improved significantly following hearing aid use. This change was not observed in control group. They concluded that hearing aid use improves cognitive function. Differences observed among studied may be due to various methodological issues such as number of participants, acclimatization time period, type of cognitive tests used etc.

In the current investigation, we also did not observe the acclimatization effect majority of the auditory skills assessed except for speech perception in noise. Our results are contradicts some of the previous research on hearing aid acclimatization (Cox & Alexander, 1992; Gatehouse, 1992, 1993; Munro & Lutman, 2005) . In the present study we compared the unaided auditory performance measured on initial fit to that after one month. This may be one of the reasons why we may have failed to observe the acclimatization effects. It may be that acclimatization effects are specific to those frequency and intensities altered by hearing aid amplification (Cox & Alexander, 1992). However, in the current study, majority of the auditory measures assessed in unaided condition. Therefore, the stimulus presented did not have typical characteristics of amplified signal that the hearing aid user was exposed. Hence, it is possible that acclimatization effects were not seen. Our results are consistent with Humes & Wilson, (2003). Humes & Wilson, (2003) examined changes in hearing aid performances and benefit in 9 participants over 3 years period. They measured number of auditory and non-auditory performance following 3 years of hearing aid use. Auditory measures included, nonsense syllables perception in quiet and in noise, connected speech test in noise and quite. They also evaluated benefit derived from hearing aid through self-reported measures of hearing aid benefit. Performance and benefit was measured at multiple sessions for 3 years. They failed to evidence any systematic improvement in hearing aid benefit over a period of time. Consistent with these studies, current investigation also failed to observe any hearing aid benefit following one month of hearing aid use.

Chapter 5 - Summary and conclusions

Improvement in hearing and related domains following hearing aid use is termed as hearing aid acclimatization. Hearing aid acclimatization is observed in auditory and speech perception skills. However, it is not known if there is a transfer of acclimatization affects to other domains such as working memory skills. This study aimed to investigate the effect of hearing aid acclimatization on some auditory and working memory skills in individuals with mild to moderate cochlear hearing loss.

A total of 14 participants with mild to moderate cochlear hearing loss in the age range of 50 to 65 years participated in the study. Of the 14 participants only 10 completed the study and hence data from only 10 participants was analyzed. All participants were naive users of hearing aids. After routine audiological evaluation and hearing aid fitment participants underwent detailed working memory and auditory assessment. Working memory and auditory assessments were done immediately after the fitment of hearing aid and after one month of hearing aid usage. All audiological evaluations and structured interview was repeated before the second assessment also. The working memory tests carried out were reading span, auditory digit span and auditory sequencing. The auditory test included gap detection thresholds, temporal modulation transfer function, pitch discrimination thresholds, duration pattern thresholds, concurrent vowel identification and speech perception in noise.

Since the data was non-normally distributed non parametric tests were used for statistical analyses. The results revealed that there was no significant change in all the working memory skills assessed before and after hearing aid use. Except speech perception in noise none of the auditory skills assessed also demonstrated significant change. Speech perception in noise significantly improved following one month of hearing aid use. These results suggest that short-term use of hearing aids have positive benefit only on speech perception in noise and it does not generalize to other domains.

Reference

Akeroyd, M. A. (2008). Are individual differences in speech reception related to individual differences in cognitive ability? A survey of twenty experimental studies with normal and hearing-impaired adults. *International Journal of Audiology*, *47 Suppl 2,* S53–S71. http://doi.org/10.1080/14992020802301142

Amorim, R. M. C., & Almeida, K. (2007). Study of benefit and of acclimatization in recent users of hearing aids. *Pró-Fono : Revista de Atualização Científica*, *19*(1), 39–48. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17461346

American National Standards Institute. (1999). Maximum permissible ambient noise levels for audiometric test rooms (ANSI S3.1-1999). New York: Author.

Arlinger, S., Gatehouse, S., Bentler, R., Byrne, D., Cox, R. M., Dirks, D. D., Willott, J. F. (1996). Report of the Eriksholm Workshop on auditory deprivation and acclimatization. *Ear and Hearing*,17(3), 87S-98S. http://doi.org/10.1097/00003446-199617031-00009

Bender, R. A., Getta, J. P., & Anderson, C. V. (2015). Longitudinal Study of Hearing Aid Effectiveness . I : Objective Measures, *Journal of Speech, Language, and Hearing Research*.*36* (August 1993), 808–819.

Bentler, R. A., Niebuhr, D. P., Getta, J. P., & Anderson, C. V. (1993). Longitudinal study of hearing aid effectiveness. II: Subjective measures. *Journal of Speech and Hearing Research*, *36*(4), 820–31. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8377494

Broadway, J. M., & Engle, R. W. (2011). Individual differences in working memory capacity and temporal discrimination. *Plos One*, *6*(10). http://doi.org/10.1371/journal.pone.0025422

Choi, A. Y., Shim, H. J., Lee, S. H., Sang, M. S., Yoon, W., & Joo, E. (2011). Is Cognitive Function in Adults with Hearing Impairment Improved by the Use of Hearing Aids ?. *Clinical and Experimental Otorhinolaryngology*, *4*(2), 72–76. http://doi.org/10.3342/ceo.2011.4.2.72

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*(5), 769–786.

Cox, R. M., & Alexander, G. C. (1992). Maturation of hearing aid benefit: objective and subjective measurements. *Ear and Hearing*, *13*(3), 131–41. http://doi.org/10.1097/00003446-199206000-00001

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*(4), 450–466. http://doi.org/10.1016/S0022-5371(80)90312-6

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2013). Unilateral and bilateral hearing aids, spatial release from masking and auditory acclimatization. *The Journal of the Acoustical Society of America*, *134*(1), 596–606. http://doi.org/10.1121/1.4807783

Divenyi, P. L., Stark, P. B., & Haupt, K. M. (2005). Decline of speech understanding and auditory thresholds in the elderly. *The Journal of the Acoustical Society of America*, *118*(2), 1089–1100. http://doi.org/10.1121/1.1953207

Doherty, K. a., & Desjardins, J. L. (2015). The benefit of amplification on auditory working memory function in middle-aged and young-older hearing impaired adults. *Frontiers in Psychology*, *6*(June), 1–9. http://doi.org/10.3389/fpsyg.2015.00721

Ellis, R. J., & Munro, K. J. (2015). Benefit from, and acclimatization to, frequency compression hearing aids in experienced adult hearing-aid users. *International Journal of Audiology*, *54*(1), 37–47. http://doi.org/10.3109/14992027.2014.948217

Ferguson, M., & Henshaw, H. (2015). Auditory training can improve working memory, attention, and communication in adverse conditions for adults with hearing loss. *Frontiers in Psychology*, *6*(May), 1–7. http://doi.org/10.3389/fpsyg.2015.00556

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: evidence from monaural fitting of hearing aids. *The Journal of the Acoustical Society of America*, *92*(3), 1258–1268. http://doi.org/10.1121/1.403921

Gatehouse, S. (1993). Role of perceptual acclimatization in the selection of frequency responses for hearing aids. *Journal of the American Academy of Audiology*, *4*(5), 296–306.

Gatten, R. E. J., Echternautch, A. C., & Wilson, M. A. (1988). Acclimatization versus acclimation of activity metabolism in a lizard. *Physiological Zoology*, *61*(4), 322–329.

Grassi, M., & Soranzo, A. (2009). MLP: A MATLAB toolbox for rapid and reliable auditory threshold estimation. *Behavior research methods*, *41*(1), 20-28.

Green DM. (1990) Stimulus selection in adaptive psychophysical procedures. J Acoust Soc Am 87:2662–2674.

Horwitz, A. R., & Turner, C. W. (1997). The time course of hearing aid benefit. *Ear and Hearing*, *18*(1), 1–11. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9058033

Humes, L. E., & Wilson, D. L. (2003). An Examination of Changes in Hearing-Aid Performance and Benefit in the Elderly Over a 3-Year Period of Hearing-Aid Use. *Journal of Speech Language and Hearing Research*, *46*(1), 137. http://doi.org/10.1044/1092-4388(2003/011)

Humes, L. E., Wilson, D. L., Barlow, N. N., & Garner, C. (2002). Changes in hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. *Journal Of Speech, Language, And Hearing Research: JSLHR*, *45*(4), 772–782. http://doi.org/10.1044/1092-4388(2002/062)

Humes, L. E., Wilson, D. L., Barlow, N. N., Garner, C. B., & Amos, N. (2002). Longitudinal changes in hearing aid satisfaction and usage in the elderly over a period of one or two years after hearing aid delivery. *Ear and Hearing*, *23*(5), 428–38. http://doi.org/10.1097/01.AUD.0000034780.45231.4B

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: a latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology. General*, *133*(2), 189–217. http://doi.org/10.1037/0096-3445.133.2.189

Kuk, F. K., Potts, L., Valente, M., Lee, L., & Picirrillo, J. (2003a). Evidence of acclimatization in persons with severe-to-profound hearing loss. *Journal of the American Academy of Audiology*, *14*(2), 84–99. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12830844

Kuk, F. K., Potts, L., Valente, M., Lee, L., & Picirrillo, J. (2003b). Evidence of acclimatization in persons with severe-to-profound hearing loss. *Journal of the American Academy of Audiology*, *14*(2), 84–99. http://doi.org/10.3766/jaaa.14.2.4

Kumar, A., Nambi, A., & HR. (2015). Critical band based frequency compression and speech perception in noise in individuals with cochlear hearing loss. Compendium of Research Funded by AIISH Research Fund, 1, 119–131.

Lindenberger, U., & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: a strong connection. *Psychology and Aging*, *9*(3), 339–55. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7999320

Lunner, T. (2003). Cognitive function in relation to hearing aid use. *International Journal of Audiology*, *42 (Suppl 1)*, S49–S58. http://doi.org/10.3109/14992020309074624

Malinoff, R. L., & Weinstein, B. E. (1989). Changes in self-assessment of hearing handicap over the first year of hearing aid use by older adults. *Journal of the Academy of Rehabilitative Audiology*,22 (1989), 54-60.

Mattay, V. S., Fera, F., Tessitore, A., Hariri, A. R., Berman, K. F., Das, S., Weinberger, D. R. (2006). Neurophysiological correlates of age-related changes in working memory capacity. *Neuroscience Letters*, *392*(1-2), 32–37. http://doi.org/10.1016/j.neulet.2005.09.025

Methi, R., Avinash, & Kumar, U. A. (2009). Development of sentencematerial for Quick Speech in Noise test (Quick SIN) in Kannada. *Journal of Indian Speech and Hearing Association*, 23(1), 59–65.

Mulrow, C. D., Tuley, M. R., & Aguilar, C. (1992). Sustained benefits of hearing aids. *Journal of Speech and Hearing Research*, *35*(6), 1402–1405.

Munro, K. J., & Lutman, M. E. (2005). Sound quality judgements of new hearing instrument users over a 24-week post-fitting period. *International Journal of Audiology*, *44*(2), 92–101. http://doi.org/10.1080/14992020500031090

Ng, E. H. N., Classon, E., Larsby, B., Arlinger, S., Lunner, T., & Rudner, M. (2014). Dynamic Relation Between Working Memory Capacity and Speech Recognition in Noise During the First 6 Months of Hearing Aid Use. *Trends in Hearing*, *18*, 1–10. http://doi.org/10.1177/2331216514558688

Ovegård, A., Lundberg, G., Hagerman, B., Gabrielsson, A., Bengtsson, M., & Brändström, U. (1997). Sound quality judgment during acclimatization of hearing aid. *Scandinavian Audiology*, *26*(1), 43–51. http://doi.org/10.3109/01050399709074974

Peelle, J. E., Troiani, V., Grossman, M., & Wingfield, A. (2011). Hearing Loss in Older Adults Affects Neural Systems Supporting Speech Comprehension. *The Journal of Neuroscience*, *31*(35), 12638–12643. http://doi.org/10.1523/JNEUROSCI.2559-11.2011

Philibert, B., Collet, L., Vesson, J. F., & Veuillet, E. (2005). The auditory acclimatization effect in sensorineural hearing-impaired listeners: Evidence for functional plasticity. *Hearing Research*, *205*(1-2), 131–142. http://doi.org/10.1016/j.heares.2005.03.013

Philibert, B., Collet, L., Vesson, J., & Veuillet, E. (2002). Intensity-related performances are modi ¢ ed by long-term hearing aid use : a functional plasticity ?. *Hearing research, 165*(1), 142-151.

Pichora-Fuller, M. K., & Singh, G. (2006). Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiologic rehabilitation. *Trends in Amplification*, *10*(1), 29–59. http://doi.org/10.1177/108471380601000103

Pinheiro, M. M. C., Iório, M. C. M., Miranda, E. C., Dias, K. Z., & Pereira, L. D. (2012). The influence of cognitive aspects and auditory processes on the hearing aid acclimatization in the elderly. *Jornal Da Sociedade Brasileira de Fonoaudiologia*, *24*(4), 309–15. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23306679

R.K., S., M.T., C., & B.E., W. (1998). Long-term versus short-term hearing aid benefit. *Journal of the American Academy of Audiology*, *9*(3), 165–171. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-0032085031&partnerID=40&md5=4affb27624f690a4355ff289d2f417bd

Rudner, M., Foo, C., Ronnberg, J., & Lunner, T. (2009). Cognition and aided speech recognition in noise: Specific role for cognitive factors following nine-week experience with adjusted compression settings in hearing aids. *Scandinavian Journal of Psychology*, *50*(5), 405–418. http://doi.org/10.1111/j.1467-9450.2009.00745.x

Salthouse, T. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society : JINS*, *16*(5), 754–760. http://doi.org/10.1017/S1355617710000706

Saunders, Gabrielle H.., Cienkowski, K. M. (1997). Acclimatization to Hearing Aids. *Ear & Hearing*, *2*(2), 129–139.

Saunders, G. H., & Cienkowski, K. M. (1997). Acclimatization to hearing aids. *Ear and Hearing*, *18*(2), 129–139. http://doi.org/10.1097/00003446-199704000-00005

Sheft, S., Shafiro, V., Wang, E., Barnes, L. L., & Shah, R. C. (2015). Relationship between Auditory and Cognitive Abilities in Older Adults. *Plos One*, *10*(8), e0134330. http://doi.org/10.1371/journal.pone.0134330

Shipstead, Z., Lindsey, D. R. B., Marshall, R. L., & Engle, R. W. (2014). The mechanisms of working memory capacity : Primary memory , secondary memory , and attention control. *Journal of memory and language*, *72*, 116–141. http://doi.org/10.1016/j.jml.2014.01.004

Smeds, K., Keidser, G., Zakis, J., Dillon, H., Leijon, A., Grant, F., Brew, C. (2006a). Preferred overall loudness. I: Sound field presentation in the laboratory. *International Journal of Audiology, 45*(May), 2–11. http://doi.org/10.1080/14992020500190144

Smeds, K., Keidser, G., Zakis, J., Dillon, H., Leijon, A., Grant, F., Brew, C. (2006b). Preferred overall loudness. II: Listening through hearing aids in field and laboratory tests. *International Journal of Audiology*, *45*(May), 12–25. http://doi.org/10.1080/14992020500190177

Taylor, B. (2007). Changes in Hearing Aid Benefit Over Time: An Evidence-Based Review. *Audiology Online*. Retrieved from www.audiologyonline.com/articles/pf_article_detail.asp?article_id=1853

Tesch-Romer, C. (1997). Psychological Effects of Hearing Aid use in Older Adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *52B*(3), P127–P138. http://doi.org/10.1093/geronb/52B.3.P127

Uhlmann, R. F., Larson, E. B., Rees, T. S., Koepsell, T. D., & Duckert, L. G. (1989). Relationship of hearing impairment to dementia and cognitive dysfunction in older adults. *JAMA, 261*(13), 1916–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2926927

Van Hooren, S. A. H., Anteunis, L. J. C., Valentijn, S. A. M., Bosma, H., Ponds, R. W. H. M., Jolles, J., & van Boxtel, M. P. J. (2005). Does cognitive function in older adults with hearing impairment improve by hearing aid use? *International Journal of Audiology, 44*(5), 265–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16028789

Vestergaard, M. D. (2006). Self-report outcome in new hearing-aid users: Longitudinal trends and relationships between subjective measures of benefit and satisfaction. *International Journal of Audiology*, *45*(7), 382–392. http://doi.org/10.1080/14992020600690977

Wilhelm, O., Hildebrandt, A., Oberauer, K., & Conway, A. (2013). What is working memory capacity , and how can we measure it ?. *Frontiers in psychology*, *4*(July), 1–22. http://doi.org/10.3389/fpsyg.2013.00433

Yund, E. W., Roup, C. M., Simon, H. J., & Bowman, G. A. (2006). Acclimatization in wide dynamic range multichannel compression and linear amplification hearing aids. *Journal of Rehabilitation Research and Development*, *43*(4), 517–36. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17123191