Role of Auditory Working Memory in Prescribing Hearing Aid Gain and Type of Compression in Geriatrics

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Abstract

The purpose of the present study was to evaluate the role of auditory working memory on the amount of gain required for obtaining best speech identification and its effect on the performance with dual and syllabic compression in elderly individuals in noise. Twenty two individuals with mild to moderate sensori-neural hearing loss were evaluated with a digit span test and were divided into two groups based on the scores; good working memory group and poor working memory group. These individuals were then fitted with a digital hearing aid in which the gain was increased until the individuals obtained best speech identification. Following this, the individuals were tested in two aided conditions for speech perception in noise; dual compression mode and syllabic compression mode; by obtaining SNR-50. Results indicated that the individuals with good working memory required lesser increase in gain to obtain best speech identification when compared to those with poor working memory (not statistically significant). Further, individuals with good working memory performed better with the syllabic compression in noise and individuals with poor working memory performed better in the dual compression mode.

Key words: *Auditory working memory, hearing aid gain, compression settings*

Introduction

The most obvious auditory deficit in elderly individuals is the presence of bilateral high frequency hearing loss (Gates, Cooper, Kannel, & Miller, 1990). In addition to this, these individuals have reduced speech identification in quiet. However, this deficit is more evident in adverse listening conditions (Gaeth, 1948). Nabelek and Mason (1981) studied the effect of noise on the word identification scores of individuals with bilateral sensori-neural hearing loss. They reported that the word identification scores decreased as a function of the signal to noise ratio.

Hearing aids are one of primary forms of rehabilitation for hearing impairment in elderly individuals. However, even with suitable amplification device, many of the elderly hearing impaired individuals reject the hearing aid. Some factors which are attributed to this include auditory factors such as hearing loss (Humes & Christopherson, 1991; Humes & Roberts, 1990), listening conditions and auditory processing (Humes, Watson, Christensen, Cokely, Halling, & Lee, 1994), and non-auditory factors such as age (Bronkhorst & Plomp, 1992), expectation and attitude towards the hearing aid (Cox, Alexander, & Gray, 2005), motivation (Rupp, Higgins, & Maurer, 1977), manual dexterity (Maurer & Rupp, 1979), social stigma (Wax, 1982) and cognitive abilities of the individual (Gatehouse, Naylor, & Elberling, 2003, 2006; Lunner, 2003; Pichora-Fuller & Singh, 2006). Humes (2002) analyzed the results of three studies of hearing aid outcomes in older adults to determine predictors of hearing aid success. For speech recognition performance, the best predictors were the degree of hearing loss, cognitive performance, and age of the subject.

Among the factors listed above, cognitive factor has gained a lot interest off late. This is because some aspects of cognitive performance tend to decline with age, and these deficits are associated with corresponding difficulties in speech comprehension. This could be to a large extent due to the resource of working memory spent in perceptual processing and few resources available for storage. For a person with hearing loss because of aging, more resource of working memory is required especially in complex tasks (Cohen, 1987).

Studies have reported the influence of cognitive factors in the selection of hearing aid features, especially, in the presence of noise. This is particularly true for compression time constants (Gatehouse, et al., 2003, 2006; Lunner & Sundewall Thoren, 2007; Cox & Xu, 2010). These studies have reported that with slow time constants, listeners who achieved lower performance on a cognitive measure tended to perform better on a sentence test. Whereas those who achieved higher performance on the cognitive measure tended to perform better using fast time constants in modulated background noise. This was attributed to the fact that the fast acting compression reduces the information carrying spectral and temporal contrasts that are

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required in speech while providing greater moment to moment audibility. For the individuals with good cognitive abilities the disadvantage of reduced contrasts is outweighed by the benefits obtained from the audibility. On the other hand, for the individuals with poor working memory, the disadvantages of reduced contrasts outweigh the audibility provided.

Though, there are studies evaluating the influence of cognitive abilities in selection of compression time constants (Gatehouse, et al., 2003, 2006; Lunner & Sundewall Thoren, 2007; Cox & Xu, 2010), these studies varied the attack time and release time, to represent fast and slow acting compression systems. In our clinic, some of the commonly prescribed hearing aids have the option of dual compression and syllabic compression. These two modes of compression in hearing aids have been evaluated in adult listeners with sensory neural hearing-impairment by Geetha and Manjula, (2005). However, there is no research evaluating dual compression system in elderly population to study the contribution of cognitive factors. Dual compression system, even though considered as a form of slow compression system, works differently when compared to either fast or slow acting system, as it involves generation of two gain-control signals, one with long attack and recovery times and the other with shorter attack and recovery times. Normally, the operation of the system is determined by the slow acting control system. However, if there is a sudden increase in sound level then the fast acting control system rapidly reduces the gain, thus, avoiding uncomfortable loudness. If the increase in sound level is brief, the gain returns to the original value determined by the overall level of the speech (Moore, 2008). Hence, we were interested to study how the performance of elderly listeners, who differed in their cognitive abilities, would vary with dual and syllabic compression in speech identification tasks in quiet and in noise.

Further, it is well known that the main aim of fitting the hearing aids is to ensure that the audibility of speech is restored due to the amplification. Several authors have studied the importance of audibility on the speech recognition performance by individuals with hearing impairment (Hogan & Turner, 1998; Turner & Cummings, 1999) and have found that increasing the audibility improves speech intelligibility with some exceptions. Even in elderly individuals, audibility has been found to be an important factor in the speech recognition ability (Souza, Boike, Witherell, & Tremblay, 2007). Hence, it can be assumed that increasing the gain of the hearing aid would result in some amount of increase in speech identification. By setting the appropriate amount of gain in the hearing aid, the individual would be provided with enough audibility for adequate speech recognition. However, whether there is any difference in gain requirement in good and poor cognitive abilities for providing best speech identification is not evaluated.

Hence, there is a need to study the influence of working memory on the selection of gain, and dual and syllabic compression system in elderly population. Such a study will help in successful prescription of hearing aids and in planning the effective rehabilitation programmes based on the needs of the elderly clients.

Method

The present study consisted of 3 stages to test the objectives of the study; Stage I-Assessment of auditory working memory in geriatric population, Stage II-Assessment of gain requirement in individuals with good and poor working memory, and Stage III-Assessment of the effect of dual and syllabic compression in the presence of noise in geriatric individuals with good and poor working memory.

Participants

Twenty two individuals in the age range of 60 to 70 years with bilateral mild-moderate sensori-neural hearing loss were considered in the study. Middle ear disorders, neurological involvement, systemic diseases and psychological problems were excluded before considering the individual as a participant.

Procedure

Stage I: Assessment of auditory working memory

The present study used digit span test from Post Graduation Institute (PGI) battery of brain dysfunction (Pershad & Verma, 1989) to assess the working memory of the participants. The test consists of two parts: digit forward test and digit reverse test. Both the tests have two sets each. The digit forward test consists of six tasks in each set. The first task has three digits. Each of the subsequent tasks increases in length by a single digit. The last task has eight digits. The digit reverse test consists of seven tasks increasing in length from two digits to eight digits. A maximum score of 16 can be achieved on the test. The test has normative values for individuals in the age range of 20 to 70 years. The testing was carried out at the most comfortable level of the participants.

The digit forward test was started from the task 1 of both the sets, first from set 1 and then from set 2. The participants were instructed to repeat the digits in the same order as the clinician instructed. The digits were read at a steady state of one digit per second. When the participants repeated the numbers in the correct order, they were asked to repeat the items from the task 2 which had four numbers from both the sets, one after the other. The same procedure was repeated until the participants failed to repeat the numbers from both the sets of the same task. The procedure for the digit reverse test was the same except that the participants were asked to repeat the numbers in the reverse order of the presentation. For the digit forward test, the score was the total number of digits in the longest series the participant repeated exactly as presented. For the digit reverse test, the score was the total number of digits in the longest series the participant repeated in reverse order. The total score was calculated by the sum of the scores in the digit forward and digit reverse tests.

Based on the total score, the subjects were grouped into either of the following two groups: *Good Working Memory Group*- Participants with scores greater than the mean minus standard deviation of the test norms. This group comprised of 12 individuals in the age range of 60 to 70 years with mean age of 64.67 years (SD=3.80). The mean digit span score in this group was 9.33 (SD=1.43). *Poor Working Memory Group*- Participants with scores lesser than the mean minus standard deviation of the test norms. This group included 10 individuals in the age range of 60 to 70 years with mean age of 66 years (SD=3.86). The mean digit span score in this group was 5.8 (SD=0.42).

Stage II: Assessment of gain requirement

A two channel digital non-linear hearing aid with the feature of dual and syllabic compression was used for the study. It was programmed using NOAH software with a Hi-Pro connected to a PC. The National Acoustic Laboratory Non-linear 1 (NAL-NL1) prescriptive formula was used to calculate the target gain.

The first fit was carried out to match the hearing aid gain to the target gain curve prescribed by NAL-NL1. To verify the adequacy of gain and frequency shaping, identification of the Ling's six sounds (Ling, 1976) was done and five unrelated questions were asked at 40 dB HL. Depending on the response, changes were made in the gain and frequency shaping. After the verification, for testing the objectives of the study, Speech Identification Scores (SIS) using the phonemically balanced word list developed by Yathiraj and Vijayalakshmi (2005) were found, in quiet, at 40 dB HL. To check how much of increase in gain was required to obtain best SIS, the gain was increased in 2 dB steps till a plateau in SIS was reached. The plateau was said to be achieved, when SIS obtained was same at two consecutive steps of increase in gain. The lower level of gain at which the plateau started was noted down. The difference between the gains at first fit and the gain at plateau for each individual was calculated, which will be referred as G_{diff} hereafter.

Stage III: Assessment of effect of dual and syllabic compression on speech identification in noise in geriatric individuals with good and poor working memory

Speech recognition in noise in different compression conditions was assessed through the signal to noise ratio-50 (SNR-50) procedure using the PB word list. This procedure was adopted from the Tillman and Olsen's (1973) procedure for speech audiometry. The gain settings of the hearing aid were those at which the subject obtained a plateau in the speech identification scores in stage II. The level of speech was kept constant at 45 dBHL. The level of the noise was varied with the initial level being 30 dB HL. The participant was instructed to repeat the words heard. The noise level was increased in 5 dB steps until a score of 50% was obtained. At this level, to get the precise value of SNR-50, the noise was varied in 2 dB steps so as to obtain 50% correct word recognition scores. The testing was stopped when the participant obtained 50% correct score in the presence of noise. The difference between the level of the speech and the noise at this stage was noted as the SNR-50. The SNR-50 for each of the participants was measured in three conditions; unaided, and aided with dual and syllabic compression settings.

Results and Discussion

The two main objectives of the present study were to evaluate the gain requirement by individuals with good working memory and poor working memory to obtain best speech identification scores, and to assess the effect of dual and syllabic compression on speech recognition in noise by geriatric individuals with good working memory and poor working memory.

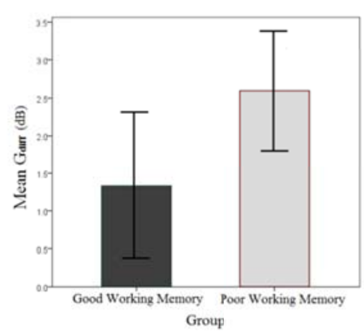

Figure 1: Mean G_{diff} between the two groups.

Table 1: Comparison of the G_{diff} in the good working memory and poor working memory groups

Group	N	Mean G_{diff} (dB)	SD	t	df	p (2 tailed)
GWM	12	1.33	1.96			
PWM	10	2.60	1.64	-1.61	20	0.122

Note: GWM: Good working memory, PWM: Poor Working Memory

Table 2: Results of Mann Whitney U test for verification of the Independent t-test

Null Hypothesis	Test	p	Decision
G_{diff} is same for both the groups	Independent Samples Mann-Whitney U test	0.081	Retain the null hypothesis

The G_{diff} was compared between the two groups (individuals with good working memory and individuals with poor working memory). Further, the speech recognition in noise measured through the signal to noise ratio-50 was compared in the three conditions of unaided, aided with dual compression and aided with syllabic compression, using statistical measures. All the statistical analysis was conducted using Statistical Package for Social Sciences (SPSS, version 18) software.

Comparison of gain requirement between the good and poor working memory groups

It can be observed from Figure 1 that most of the individuals in the good working memory group achieved a plateau of SIS at first fit itself. Even those individuals who required gain increase, required lesser increase in the gain to achieve a plateau of SIS when compared to poor working memory group. On the other hand, most of the individuals with poor working memory required increase in the gain to achieve a plateau in the SIS.

Independent t-test was done to see if this difference is statistically significant. Table 1 shows the results of the independent t-test along with the mean and standard deviation of the two groups. It can be seen from Table 1 that the G_{diff} was not statistically significant. Further, as it can be observed from Table 1, the standard deviation is greater than the mean and, hence, a nonparametric test is needed to verify the results of the independent t-test. Mann Whitney U test was conducted to verify this. The results of Mann Whitney U test are given in Table 2.

It can be seen from Table 2 that even Mann Whitney U test did not show statistically significant difference in the amount of gain required to obtain best SIS between the two groups ($p>0.05$).

Though there was a difference in G_{diff} between the two groups, this difference was not statistically significant. The reason for this may be that the evaluation was done in a quiet situation. Studies show that under favourable listening conditions, the speech signal can be immediately matched to the stored representations in long term memory even in the elderly population. However, in adverse listening conditions this matching process may fail (Rudner, Foo, Sundewall-Thoren, Lunner, & Ronnberg, 2008). In such conditions, there may be a difference in the amount of information understood depending on the cognitive ability of the individual. Hence, testing in adverse listening conditions which is more close to real world situations might give a clearer picture on the effect of cognition on the gain requirement. However, in the present study, the gain requirement could not be assessed in noise, as it required many number of word lists in Kannada, and in Kannada language, at present, there are only four word lists available.

Evaluating the effect of dual and syllabic compression on SNR-50 in the two groups:

In order to evaluate the effect of dual and syllabic compressions, comparisons were done between the two groups and also within the groups.

Here, it should be noted that more negative the value of SNR-50, better is the performance. From Figure 2 it can be observed that the scores in the dual and syllabic compression conditions are better than the unaided condition. Further, in all the three conditions (unaided, dual compression mode and syllabic compression mode), the individuals in the good working memory group performed better than the individuals in the poor working memory group. MANOVA was done to verify if this difference was statistically significant. The results of MANOVA are given in Table 3.

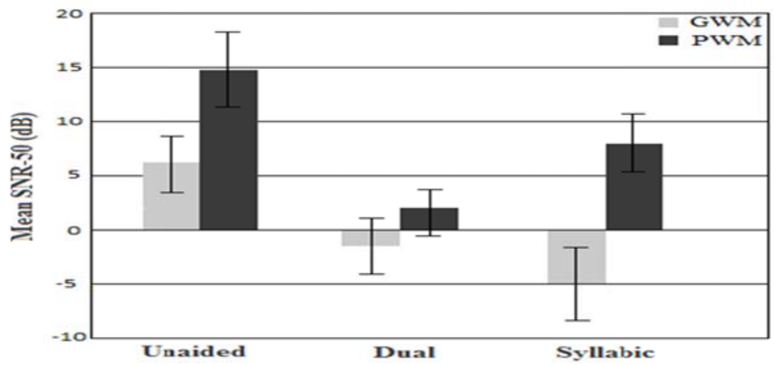

Figure 2: Mean SNR-50 for good working memory (GWM) group and poor working memory (PWM) group in unaided, dual and syllabic compression.

Table 3: Comparison of unaided, dual compression and syllabic compression using MANOVA between the two groups

Source	Dependent variable	F (1,20)	p
Groups (GWM & PWM)	Unaided	11.133*	0.003
	Dual	2.025	0.170
	Syllabic	26.114*	0.000

*Note: *- p<0.05; GWM - Good Working Memory and PWM- Poor Working Memory*

Between the group comparison of SNR-50 for dual and syllabic compression conditions: Figure 2 shows the mean and standard deviation of the signal to noise ratio-50 values obtained in unaided, dual and syllabic compression conditions. In the analysis, even the unaided condition was included to ensure that there was no degradation of speech recognition. Scores in the aided condition because of the amplitude compression of the hearing aid.

Table 3 shows that there is a statistically significant difference between the good and poor working memory groups for the unaided and syllabic compression conditions at 95% confidence interval ($p<0.05$). That is, the individuals in the good working memory group performed significantly better than the individuals in the poor working memory group. These results are supported by other studies, which report that in adverse listening conditions, the individuals with a good cognitive capacity require lesser signal to noise ratio to obtain 50% performance (Lunner, 2003; Rudner, Foo, Ronnberg, & Lunner, 2007; Rudner, et al., 2008). Poor performance with fast-acting compression in individuals with poor working memory may be because the fast acting compression introduces changes in the amplitude of formants (Lindemann & Worrall, 2000) and reduces the intensity contrasts and modulation depths of speech, which may have an adverse effect on the speech perception cues (Plomp, 1988).

However, there was no statistically significant difference found for the dual compression condition between the two groups for the dual compression conditions ($p>0.05$). These results support the findings of earlier studies (Gatehouse et al., 2003; 2006; Lunner & Sundewall-Thoren, 2007; Cox & Xu, 2010). In dual compression mode, the temporal envelope of the speech is not distorted and, hence, the syllable features are preserved (Drullman, Festen, & Plomp, 1994). Further, the short term changes which convey information in the spectral patterns of speech sounds are not distorted (Kluender, Coady, & Kiefte, 2003). These features are important in maintaining the speech intelligibility. Thus, even the individuals with poor working memory were able to obtain good scores in the dual compression mode.

Within the group comparison of SNR-50 for dual and syllabic compression conditions in good working memory group: Repeated measures ANOVA was done to compare the performance with unaided, dual and syllabic conditions within the group. It can be observed in Table 4 that there is a statistically significant difference found between the unaided, dual and syllabic compression conditions for the good working memory group ($p<0.05$). To find out which of the conditions were differing, Bonferroni's post-hoc analysis was done.

Bonferroni's post-hoc analysis revealed that unaided, dual compression and syllabic compression are significantly different from each other ($p<0.05$). It can also be observed that the good working memory group

Table 4: *Results of Repeated measures ANOVA comparing SNR-50 for good working memory group*

Condition	Mean SNR-50 (dB)	SD	F (2,22)	p
Unaided	6.08	5.45		
DC	-1.42	5.56	50.384*	0.000
SC	-5.00	6.09		

*Note: *- p<0.05; DC- Dual Compression and SC- Syllabic compression*

Table 5: Bonferroni's post-hoc analysis comparing SNR-50 for good working memory group

Condition (I)	Condition (J)	Mean Difference (I-J)	p
Dual	Syllabic	3.583*	0.012
	Unaided	-7.500*	0.000
Syllabic	Dual	-3.583*	0.012
	Unaided	-11.083*	0.000
Unaided	Dual	7.500*	0.000
	Syllabic	11.083*	0.000

Table 6: Results of Repeated measures ANOVA comparing SNR-50 for poor working memory group

Condition	Mean	SD	F (2,22)	p
Unaided	14.80	6.81		
DC	2.00	5.56	44.013*	0.000
SC	8.00	5.75		

*Note: *- p<0.05; DC- Dual Compression, SC- Syllabic Compression*

Table 7: Bonferroni's post-hoc analysis for poor working memory group

Condition (I)	Condition (J)	Mean Difference (I-J)	p
Dual	Syllabic	-6.000*	0.000
	Unaided	-12.800*	0.000
Syllabic	Dual	6.000*	0.000
	Unaided	-6.800*	0.002
Unaided	Dual	12.800*	0.000
	Syllabic	6.800*	0.002

*Note: *: p<0.05*

performed better with syllabic compression than with dual compression, as given in Table 5. These findings are supported by the findings of earlier studies (Gatehouse, et al., 2003; 2006; Lunner & Sundewall-Thoren, 2007; Rudner et al., 2008; Cox & Xu, 2010) who also found that individuals with good working memory match the distorted information to the long term memory storage and still perceive the entire information.

As mentioned earlier, syllabic compression introduces amplitude fluctuations in the different frequency bands as well as reduces the amplitude modulation depth and intensity contrasts (Stone & Moore, 2003). Hence, higher cognitive skills are required to understand the entire message. Hence, in the present study, the group with good working memory perform better with syllabic compression.

Within the group comparison of SNR-50 for dual and syllabic compression conditions in poor working memory group: Repeated measures ANOVA was done to compare the performance with unaided, dual and syllabic conditions within the group. It can be observed in Table 6, there is a statistically significant difference found between the unaided, dual and syllabic compression conditions for the poor working memory group ($p<0.05$). To find out which of the conditions was significantly different, Bonferroni's post hoc analysis was done.

The post hoc analysis results are shown in table 7. It can be observed that the individuals with poor working memory performed better with dual compression than with syllabic compression. These individuals did not have sufficient cognitive capacity to match the distorted information to the long term memory. Thus, these individuals are able to obtain better scores in this condition, because the dual compression mode has more preserved phonological characteristics. Further, it is evident from the above finding that, though the dual system involves the generation of two gain control signals, its operation is more like the slow acting compression system. These results are again correlated with earlier studies (Gatehouse et al., 2003; 2006; Lunner & Sundewall-Thoren, 2007; Rudner et al., 2008; Cox & Xu, 2010).

Conclusions

It can be concluded from the above findings that the gain requirement may not be different between individuals with good and poor working memory in quiet. In complex listening situation, there may be a difference. However, this needs to be researched upon. Further, it can also be concluded that it is important to consider the cognitive abilities of the individual while setting the compression time constants. Therefore, a simple test of cognition must be included in the audiological test battery especially while evaluating elderly individuals. This knowledge will help in better prescription and fine tuning of hearing aids.

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