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# CAN WORKING MEMORY CAPACITY PREDICT SPEECH PERCEPTION IN PRESENCE OF NOISE IN OLDER ADULT?

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**Abstract**

This study explored whether speech understanding can be predicted by working memory. A total of 21 older adults with a mean age of 69 years (Standard deviation (SD)= 10.4 years) were recruited. The Reading Span test conducted in English was translated to Odia. Each sentence consisted of three to five words. Three to six sentences were presented with increase in number of sentences as the test progressed. Half of the sentences were coherent. The participants judged whether the sentences were semantically correct within 1.75 seconds of presentation. After completion of a series of sentences, the participants recalled the word presented either at the beginning or end of the sentence. A spondee and Phonetically Balanced list in Odia was used to determine the Speech Recognition Threshold (SRT) and Word Recognition Score (WRS), respectively. Pure-tone audiometry (PTA), SRT and WRS was conducted followed by the reading span test. Speech noise was introduced during WRS testing at three levels of noise, i.e., (a) 0 dB, (b) -10 dB and (c) -20 dB SNR (signal to noise ratio). The reading span score corelated with WRS measured at three noise levels. Pure -tone audiometry accounted for 78% of the variance in WRS in quiet. The reading span scoreaccounted for nearly 80% of the variance in WRS in presence of noise at higher levels. The most striking finding is that the working memory explained the variance in speech perception score at higher noise levels, while in quiet, hearing loss explained the variance in speech perception.

**Keywords:** Cognition, Hearing Loss, Reading Span Test, Working Memory.

## 1. Introduction

Hearing loss concomitant with ageing generally results in perception of diminished quality of speech even if they are audible. Furthermore, these problems are exuberated in presence of background noise (Nixon et.al., 2019; Glyde et.al., 2013; Besser et.al., 2015; Kortlang, Mauermann et.al.,2016; Lesicko& Llano 2017). The field of Otology and Audiology has mainly focused on measurement of hearing sensitivity and word repetition to examine speech perception in individuals that may not reflect the communicative performance of an individual in real life. Speech understanding is a complex procedure wherein the initial part of the incoming stimuli has to be stored in the memory until the remaining message is delivered so that appropriate speech understanding can occur (Pichora-Fuller, 2006). In this context, hearing scientist have realised the importance of the role played by cognition in audition.

### 1.2 Cognition and Speech recognition

In older adults, the performance on the speech scores declines owing to the perceptual problems evident in old age and also due to the depletion of working memory resources with ageing (Pichora-Fuller& Singh, 2006; Iliadou et.al., 2018, 2019). In the last few decades, research has shown that understanding of speech presented with interfering noise is related to cognitive capacity, especially working memory in adults with age-related hearing loss (Akeroyd, 2008; Mishra et.al., 2013, a, b; Pichora-Fuller, 2008; Pichora-Fuller & Singh, 2006). This is evident more in the elderly adults as poor sensory input concomitant with age- related hearing loss results in the greater use of cognitive resources for understanding of speech. The working memory capacity is limited and it performs both the functions of memory and processing for a short duration of time (Baddeley, 2012). It has application in all human activities including speech perception (Baddeley, 2003). Although various mechanism of the complex interaction of cognition have been hypothesized (c.f. Nixon et.al., 2019; Pichora-Fuller & Singh, 2006), these complex interaction of cognition and speech understanding has been very lucidly described in the Ease of Language Understanding model (ELU; Rönnberg, 2003; Rönnberg et.al., 2010, 2013, 2016, 2019). This model hypothesises that either language understanding or speech recognition is effortless when the incoming stimuli matches with the stored representation of language in the memory system of an individual. However, in adverse listening conditions, such as in presence of background noise, reverberation, hearing loss, or co-existence of more than one difficult-to-listen condition, cognitive resources are employed for speech understanding. In particular, the ELU model predicts that in unfavourable listening conditions, speech recognition essentially requires involvement of working memory and its central component, executive functions (Rönnberg et. al., 2016, 2018). Mishra et. al., (2013 a) have emphasized that the executive function of updating, shifting and inhibition is involved in speech perception. These hypotheses suggest that as the level of difficulty in listening increased with increment in noise levels, the reliance on working memory for speech perception increases. This may be because the listeners have to decipher either the words or the sentences from the fragments of undeteriorated segments of the stimuli (Pichora-Fuller, et.al., 1995). With greater deteriorated speech signal, for example, with greater noise levels, the dependency on working memory capacity for speech recognition is likely to increase. Performance in working memory tests have generally been found to be a very good estimator of perception of speech presented with interfering noise in persons with hearing loss (Lunner, 2003; Lunner&Sundewall-

Thorén, 2007; Gatehouse, et.al., 2003, 2006a, 2006b; Foo, et.al., 2007; Rudner, et.al., 2008; Rudner, et. al., 2009, 2011; Rönnberg, et. al., 2011; Arehart et.al., 2013).

**1.2Working Memory Capacity**

Reduced functioning of the peripheral mechanism, such as hearing loss, may affect measure of cognition. It is necessitated that the cognition should be evaluated through a sensory channel that is intact. However, cognition is often evaluated through auditory modality and if the hearing sensitivity is reduced then it will lead to inaccurate measurement of cognition. Hence, when we are evaluating association of speech recognition and cognition, a different modality, for example, visual modality should be used for measurement of cognition. Hence, in hearing sciences, researchers have generally used the reading span test for measuring the working memory.

In the first variant of reading span test, after completion of a series of sentences, the participants recalled the word either at the beginning or at the end of the sentence (Daneman & Carpenter, 1980). Working memory capacity was measured by the total words recalled correctly in any random order. Thus, only the memory subset of the working memory was assessed. Presently used reading span test includes processing and storage components, wherein it is necessary to identify the semantic correctness of the sentences and recall of words (Besser, et al., 2012; Andersson, 2001). Recent research on recall of sentences presented along with interfering noise demonstrated that the recall performance correlated with working memory capacity across various age span either with or without hearing loss (Rönnberg, et.al., 2012; Ng, et.al., 2013). We used the reading span test to assess the working memory capacity.

While the correlation between speech perception in presence of competing background noise and working memory is well established for English and other European languages, especially for elderly adults, we hypothesize that similar correlation exists for Indian languages as well. However, to the best of our knowledge, there has been limited work conducted in this dimension. Firstly, to validate this hypothesis, we selected the Odia language, spoken over by 35 million people primarily those residing in the state of Odisha, India. Secondly, in previous studies conducted, lower levels of noise were used and emphasis was placed on maximising audibility. We expected that the reliance on working memory capacity will be greater for perception of speech presented in higher level of noise in this study that is in agreement with previous hypotheses (Rönnberg, 2003; Rönnberg et.al., 2010, 2013, 2016, 2019). The aim of this present study is two -fold. Firstly, the reading span test conducted in English was translated and adapted to Odia. Secondly, it explored whether the working memory test predicted speech perception score in the presence of noise in older adults with hearing loss.

**2.Methods**

**2.1 Participants**

Thirty-two students including 11 females (mean (M) =18 years; standard deviation (SD) = 1.85; Range: 16-25 years) were included in the study.

The subjects had hearing threshold within normal limits (thresholds were less than 25 dB in both the ears). Odia was also their first spoken language. No previous history of any psychological and cognitive impairment was reported. The subjects had either completed or were undergoing graduate studies. Listeners aged 50 years or older, who spoke Odia as their first language, with no previous history of cognitive and vision problem were also recruited. This group included 21 adults including 18 males (M=69 years; SD+=0.4; Range: 50-78 years). Those participants, who required minor correction in vision, wore their spectacles during the test.

**2.2 Material**

**2.2.1 Reading Span Test.**

In this study, the English version of the reading span test was translated and adapted to Odia, and was used to assess the working memory span. These translations were performed by a linguist. These translated Odia sentences were verified by three under graduate students who were fluent both in English and Odia. The participants were shown the sentences of the reading span test on a laptop screen in white clear background; moreover, the words were presented as images prepared in form of a video in black font. The participant read aloud the sentences as shown on the screen wherein one sentence was presented at a time. The participant identified if the sentence was coherent by responding either to a "Yes" or absurd by responding to a "No" within 1.75 seconds after each sentence completely appeared on the screen. There were 57 sentences presented in total and the first three sentences were trial sentences. The participants practiced the trial sentences until they understood the instruction provided to them. Each sentence consisted of three to five words. Furthermore, three to six sentences were presented at a time, after which the participants recollected either the first or the last word of each sentence. As the test progressed, the series length was increased. Each word was presented for 800 milliseconds and there was an interval of 50 milliseconds between the words presented. Half of the sentences were coherent ("Adhinakdekhile tanka danga" in Odia translated as "The captain saw his boat") and the other half of the sentences were absurd ("Botaltipiilapani in Odia translated as "The bottle drank water"), which were spread randomly across all the sentences. Few of the words in English such as skiing, canoe, pear etc, were replaced with similar articles commonly used in the region of Odisha. After completion of a series of sentences, the participants recalled the word either at the beginning or at the end of the sentence. Working memory capacity was measured by the total words recalled correctly in any random order. A written instruction was developed in order to maintain the uniformity. Clarification was provided wherever the subjects sought for it.

**2.2.2 Spondee list**

The spondee word list developed by Dash (2019; unpublished master dissertation) was used as the test material to establish the Speech Recognition Threshold (SRT). The list consists of 50 commonly used words in Odia. All the participants were presented with the words in the same order.

**2.2.3 Phonetically Balanced (PB) word list**

The PB word list developed by Behera (2004; unpublished master dissertation) was used as a stimulus to determine the Word Recognition Score (WRS). The list consists of 50 words used in Odia and all the participants were presented with the words in the same order.

The initial results were presented at the Indian Speech and Hearing Association annual conference (Chandigarh, 15$^{th}$ February, 2020). The ethical committee of the conference approved the study for presentation.

**3. Procedure**

A written consent for participation in the test was obtained from the subjects after they were explained about the study. They were informed to take small breaks whenever they desired in between the tests. Pure-Tone Average (PTA) was determined by conducting Pure-tone Audiometry on arrival. The air conduction (AC) thresholds were obtained followed by bone conduction (BC) to rule out conductive pathology. The AC and BC testing was carried out using the Telephonic TDH 39 headphone and RadioEar B71 bone vibrator, respectively, using a dual channel audiometer (Maico MA 42). The SRT and WRS scores were obtained using a live voice using the same tester for all the participants; moreover, the same audiometer and TDH 39 headphones. Firstly, the SRT levels were obtained and then the WRS levels were obtained at a level 20dB higher than the SRT levels. Speech noise, as available in the audiometer, was introduced during obtaining WRS; furthermore, noise was presented at three levels of noise (0 dB SNR, -10 dB SNR, and -20 dB SNR). Secondly, the same list was administered at three noise levels. The PB words in Odia were very similar to the sound. The noise levels used in the study were high, hence, it can be assumed that the learning effect was minimised in the study.

Finally, administration of reading span test in Odia concluded the testing. The total testing time ranged between 75 and 90 minutes for all the participants with at least one break taken. None of the participants complained either of fatigue or tiredness. The order in which the tests was administered was same for all the participants. All these procedures were conducted in a sound-treated chamber. The testing on the young normal hearing adults was carried out to determine the noise presentation levels for the older adults. Furthermore, it was used to ascertain the validity of the developed reading span test in Odia to older adults with hearing loss.

Statistical Package for the Social Sciences (SPSS; version 20) was used for the statistical analysis. As the scores of the young adults on speech recognition tasks had a ceiling effect, further analysis of the scores was not carried out. As the SRT scores obtained by the older adults with hearing loss followed normal distribution (Studebaker, 1985), further statistical analyses were employed. In order to examine the association of the reading span score with PTA, SRT and SDS, a correlation analysis was performed wherein significance level of 0.01 was considered significant. Furthermore, to estimate the contribution of working memory in speech recognition, hierarchal regression model was employed.

**4. Results**

The working memory was assessed by the newly developed reading span test in Odia. The mean reading span score for the young adults was 21 (SD: 3.85; Range: 16-31 words). The mean PTA for the young adults was 20 dB HL (SD: 3.29; Range: 15-25 dB HL), mean SRT was 20 dB HL (SD: 4.74; Range:15-25 dB HL), and mean WRS was 95% (SD: 4.01; Range: 90-100%) for both ears; and the speech performance measured by WRS at the three noise levels (0 dB SNR, -10 dB SNR & -20 dB SNR) is shown in Table 1.

| **Test** | **Mean** | **Standard Deviation** |
|---|---|---|
| Pure Tone Average | 20 | 3.29 |
| Reading Span Score | 21 | 3.85 |
| Reading span semantic judgement | 51 | 4.15 |
| Speech Recognition Threshold | 20 | 4.74 |
| Word Recognition Score (0 dB SNR) | 95 | 4.01 |
| Word Recognition Score (-10 dB SNR) | 84 | 7.23 |
| Word Recognition Score (-20 dB SNR) | 78 | 3.45 |

**Table 1:** Mean and the standard deviation of the accuracy in the Pure Tone Average, Reading Span Test, Speech Recognition Threshold, Word Recognition Score at 0 dB SNR, at -10 dB SNR, at -20 dB SNR, respectively, in the younger population.

For the older adults, the mean PTA was 36.26 dB HL (SD: 16.36; Range: 22-83.5 dB HL), mean SRT was 42.5 dB HL (SD: 14.44; Range: 30-80 dB HL), and mean WRS was 79.5% (SD: 8.38; Range: 70-100%) for both the ears. The mean reading span score for the elderly adults was 16 (SD: 4.34; Range: 15-28 words). Table 2 shows these results along with WRS at the three noise levels (0 dB SNR, -10 dB SNR & -20 dB) SNR.

| Test | Mean | Standard Deviation |
|---|---|---|
| Pure Tone Average | 36.26 | 16.36 |
| Reading Span Score | 16 | 4.34 |
| Reading span semantic judgement | 51 | 4.15 |
| Speech Recognition Threshold | 42.5 | 14.44 |
| Word Recognition Score (0 dB SNR) | 79.5 | 8.38 |
| Word Recognition Score (-10 dB SNR) | 75.28 | 12.75 |
| Word Recognition Score (-20 dB SNR) | 69.23 | 11.58 |

**Table 2:** Mean and the standard deviation of the accuracy in the Pure Tone Average, Reading Span Test, Speech Recognition Threshold, Word Recognition Score at 0 dB SNR, at -10 dB SNR, at -20 dB SNR, respectively, in older adults.

There was an association between SRT and PTA (r (20) =0.97, p<0.01). There was a strong negative correlation between PTA and WRS at the three levels of SNR, 0 dB (r (20) =-0.89, p<0.01), -10 dB (r (20) =-0.84, p<0.01) and -20 dB (r (20) =-0.74, p<0.01). The reading span score corelated significantly with WRS at all the three SNR levels, i.e., 0 dB (r (20) =0.70, p<0.01), -10 dB (r (20) =0.87, p<0.01) and -20 dB (r (20) =0.92, p<0.01). Table 3 shows all these correlations.

| | Speech Recognition Threshold | Word Recognition score at 0 SNR | Word Recognition score at -10 SNR | Word Recognition score at -20 SNR |
|---|---|---|---|---|
| Pure Tone Average | 0.97** | -0.89** | -0.84** | -0.74** |
| Reading Span Test | -0.65** | 0.70** | 0.90** | 0.92** |

**. Correlation is significant at the 0.01 level (2-tailed)

**Table 3:** The correlation of the Pure Tone Average, Speech Recognition Threshold, Word Recognition Scores and the Reading Span Test

Hierarchical regression model was also used to examine the association between reading span score and WRS at three SNR levels. At 0 dB SNR, PTA predicted for 78% of the variance in WRS, while at -10 dB SNR, PTA, age and reading span score predicted for 83% of the variance in WRS, with reading span accounting for 78% of the variance in score. Finally, for WRS at -20 dB SNR, PTA, age and reading span score predicted for 85% of the discrepancy in WRS, with reading span accounting for 80% of the variance in score.

**5. Discussion**

To evaluate the association of working memory capacity and speech perception in noise performance, the reading span test in English was developed and adapted in Odia to suit the socio-cultural structure of Odisha in this study. The scores obtained in the developed reading span test in Odia were almost identical to those obtained with the reading span test in other languages (Mishra, et.al., 2013 a, b, 2014; Ng, et.al., 2013), for adults across all age groups. While the previous studies demonstrated from a non-existant to moderate association of reading span test and speech recognition in presence of noise (Foo, et.al.,2007; Rudner, et.al., 2009, and 2011), this study demonstrated a stronger correlation between reading span and speech recognition in presence of noise. The association of speech recognition in presence of noise was stronger with reading span scores as the difficulty was raised by increasing the noise levels. This finding suggests that as the level of difficulty in listening increased with increment in noise levels, the reliance on working memory for speech perception increased. This may be because the listeners had to decipher the words from the fragments of undeteriorated segments of the stimuli (Pichora-Fuller, et.al., 1995).

The most significant finding of this study is that either the working memory capacity or the reading span score could explain 80% of the discrepancy in speech perception as measured by WRS at higher noise levels, whereas discrepancy in speech perception was explained by hearing loss at the lowest noise level (0 dB SNR). In order to compensate the perceptual difficulties of speech as

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experienced by the older adults with hearing loss (Nixon et.al., 2019; Glyde et. al., 2013; Besser et.al., 2015; Kortlang, Mauermann et.al., 2016; Lesicko and Llano 2017), older adults make use of their cognitive resources, especially working memory (Mishra et.al., 2013 a, b; Pichora-Fuller, 2008; Pichora-Fuller & Singh, 2006). This finding is in congruence with the ELU model (Rönnberg, 2003; Rönnberg et.al., 2010, 2013, 2016, 2019), where reliance on the cognitive resources increases as the listening condition is worsened. The reliance on working memory for speech perception may be greater in this study compared to the previous study; as in this study, the person with hearing loss heard the stimuli unaided. In previous studies, the participants were fitted with amplification devices; hence, the auditory perception of the stimuli was partially, if not completely, restored. Firstly, Pichora-Fuller and Singh (2006) have suggested that the reliance on working memory decreased when the perceptual listening capabilities were increased. Secondly, higher noise level was used in this study compared to the studies conducted in the past. Therefore, the signal was deteriorated to a greater extent due to increased noise levels. Thirdly, the materials used to measure speech perception were PB words, whereas other studies have used sentences as stimuli. PB words have low predictability, and hence are more difficult to guess. This finding is in similar lines to that of Foo et.al., (2007), whereas reading span test predicted speech recognition in presence of noise for sentences with low redundancy and not for sentences where the redundancy was high. Foo et. al., (2007) had found that the reliance on working memory was greater with low predictability Hagerman sentences and no reliance was evident when highly predictable Hearing in Noise Test (HINT) sentences were used. This finding suggests that a higher contribution of working memory can be expected when the difficulty in listening was increased and predictability of stimuli material is lower. Owing to the increased perceptual difficulties of perception of speech stimuli in this study, such a significant association working memory and speech recognition in presence of noise was revealed that was not previously observed in other studies.

The correlation of pure tone average and speech perception was negative, thus, suggesting that as the hearing loss increased, the speech perception was reduced. This finding is within the expected lines. Correlation between hearing loss and speech measures is within the expected lines. Similarly, the young adults had greater mean working memory capacity as compared to older adults as expected (Ng, et. al., 2013; Mishra, et. al., 2013, a; b, 2014).

## 6. Conclusion

In this study, reading span test was established in Odia. The study demonstrated that working memory predicted speech recognition in presence of interfering noise observed in previous studies. The most striking finding of this study is that the reliance on working memory capacity by older adults for understanding of speech increased as the level of noise increased. At lower noise levels, the hearing level predicted the speech performance. This finding has not been reported in previous studies. In earlier studies, lower-level noises were used to replicate real- life listening conditions of elderly adults with hearing loss. The stimulus difficulty was also increased in this study by using words as stimuli material instead of sentences and also using higher level of noise. The drawback of this study is that the participants were tested with live voice due to non-availability of recorded stimuli material. However, the same speaker was always used throughout the testing. The working memory test was translated and adapted to Odia language, which can be used in further studies. Furthermore, it may predict hearing aid outcome for adults with hearing loss.

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