Comparison of Working Memory Abilities in Adults Who Do and Do Not Stutter

Dhatri S.D., Ajith Kumar U., Santosh M.[1]

Departments of Audiology and [1]Speech Language Sciences, All India Institute of Speech and Hearing, Mysore, Karnataka, India

Abstract

Introduction: Adults with stuttering (AWS) exhibit longer reading rates and poor nonword recognition. This is attributed to deficits in phonological working memory abilities specific to language disturbances. In the present investigation, working memory abilities of AWS was investigated using n‑back test which is not sensitive to subtle language deficits. **Methods:** Participants included nine AWS in the age range of 18–26 years, and nine age, gender, and language‑matched adults who do not stutter. The participants performed auditory 1‑ and 2‑back tasks, where they pressed a button whenever the same syllable was heard as the one and two syllables before, respectively. The reaction time, accuracy, false alarm rate, and d prime (difference in z‑scores of hit rate and false alarm rate) were calculated for an individual participant in each n‑back condition. **Results:** Results revealed significant difference between two groups only during 2‑back task. Analysis showed that AWS had more false alarms, which might have resulted because of the anxiety in responding, due to increased attentional demands, which is in turn reflected as working memory deficits during the difficult task. **Conclusion:** The present results provide preliminary evidence for auditory working memory deficits in persons who stutter.

Keywords: N‑back, stuttering, working memory

Introduction

Working memory refers to "a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning."[1] The working memory model explains how memory and language are interlinked through phonological loop.[2] Empirical evidence shows that adults with stuttering (AWS) exhibit longer reading rate and poor nonword recognition.[3-12] The poorer performance in them might be due to deficits in phonological working memory abilities as phonological coding along with visual information storage, and sentence comprehension is crucial for reading tasks. It has been shown that reading rate (time taken to read) can strongly predict memory span.[13] The silent reading rates were longer in AWS when compared to fluently speaking individuals.[3] When silent reading rates were correlated with nonword recall and recognition time, AWS showed decreased performance.[4]

A study assessing recall accuracy and rate of novel word learning using two multisyllabic nonwords in AWS showed significantly poorer recall accuracy and a slower rate of learning in contrast to fluently speaking individuals in nonword repetition task.[8] As nonword repetition involves phonological loop where there is retrieval of already stored phonological elements,[14] ruling out the effect of semantic content or knowledge,[15] these results indicate phonological memory deficits in AWS. Although phonological memory is an independent entity by itself, not directly related to speech production, it has been evidenced that motor processing happens during subvocal rehearsals even when there is no spoken output.[16,17] A study found that there was an effect of motor imagery which was provided in terms of interference (articulatory suppression and finger tapping) during a novel auditory‑verbal imagery task (to indicate the syllable which had stress) which shows the role of subvocalization.[16] A recent study has shown the influence of working memory on fluency in AWS which serves as an

Address for correspondence: Ms. Dhatri S. Devaraju,
Department of Audiology, All India Institute of Speech and Hearing,
Mysore, Karnataka, India.
E‑mail: dhatri2612@gmail.com

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evidence linking working memory and speech fluency.[18] It has been modeled that, to mediate speech, phonological memory recycles information between input and output components through two phonological buffers.[19] The input to phonological memory is also provided through auditory pathways where auditory working memory plays a major role in phonological processing. However, all these processes are interlinked and work as a whole.

Performance on reading rate and nonword recognition tasks in AWS indicates deficits in phonological working memory.[9-12] However, performance on these tasks tends to be affected by the underlying language disturbances also. All these tasks examined previously need good language processing skills which AWS are found lacking.[20,21] Most of the tasks are visual based, which examines only a part of the sensory input loop of phonological working memory involving visual mode. Moreover, these tasks encompass memory span measures which share a complex range of processes. Therefore, it is necessary to use a tool to test working memory skills in AWS, which is not affected by or sensitive to the language disturbances found in them.

N-back test is one of the working memory tests that would allow us to assess working memory and is not sensitive to subtle language deficits. The n-back test was originally developed by Kirchner,[22] where the age differences in short-term memory were assessed. It became popular when the cognitive neuroscientists started using the task to assess neurobiological correlates of working memory through neuroimaging techniques.[23-27] In the classic n-back task, an individual is presented with a series of stimulus and the individual's task is to respond with a button press whenever a particular stimulus is same as "n" trials before. The "n" can vary anywhere between 1 and any integer but is often increased till 3, after which it becomes very taxing for the individual. The series of stimuli used in the literature are either visual, visuospatial, olfactory, or auditory. Dual n-back tasks have been used where the combination of different modalities in stimuli presentation is adapted to assess two independent inputs of working memory.[28] In AWS, experiments which have used dual-task paradigm have either focused on the effect of working memory on phonological processing[9] or fluency.[18] The working memory tasks chosen in these studies are visual based and are so simple that both AWS and who do not stutter (AWNS) performed at the ceiling, having around cent percent accuracy showing no significant differences between them. Studies assessing phonological memory by increasing the load in terms of length of nonwords show deficits in AWS during nonword repetition and elision tasks as the length of nonwords increased.[10-12] However, these studies have language influences on working memory. A review article by Bajaj[29] has discussed how working memory deficits might be reflecting as phonological deficits and its importance in the sensory-motor processing in AWS. Given that, the auditory n-back test would allow us to assess exact neural networks involving working memory assessing through auditory modality, ruling out the language effects in AWS. Among healthy participants, there is increased activation in the prefrontal cortex as the n increases, which has been demonstrated in neuroimaging studies investigating working memory load.[24-26] The increasing load can distinguish the neural activations not only among healthy participants but also the researchers have found behavioral n-back test worthwhile in distinguishing healthy controls from schizophrenic individuals with dorsolateral prefrontal cortex dysfunction.[27,30] Thus, the auditory n-back task can be a useful tool to assess working memory abilities in various other clinical population like AWS. As the population with stuttering show sensory deficits, studying working memory using auditory n-back task might have a role in understanding the sensory-motor interplay in them. Hence, the aim of the present study was to assess the working memory using the auditory n-back test in AWS.

Methods

Participants

Participants included nine AWS (8 males and a female) in the age range of 18–26 years, and nine age- and gender-matched adults AWNS. The severity of stuttering in AWS group, as diagnosed by a qualified speech-language pathologist ranged from mild-to-severe according to Stuttering Severity Index-3 (SSI-3).[31] All the participants were right handed. None of the participants had any history/presence of gross neurological, otological, or psychological problems. Their hearing thresholds were within 15 dB HL across all octave frequencies from 250 to 8000 Hz and had speech identification scores of more than 80%. Informed written consent was obtained from all the participants before inclusion in the study.

Stimuli

Six different consonant-vowel (CV) syllables -/pa/,/ṭa/,/ka/,/ba/,/ḍa/,/ga/, were recorded by a male speaker in Adobe Audition 3.0 (Adobe Systems Inc.,) using Microbook II (Motu Inc.,) connected to a Behringer B-2 PRO condenser microphone at a sampling rate of 44100 Hz. These six syllables were used as they occur in all Indian languages and span the three distinct places of articulation from velar to retroflex to bilabial. The voiced and unvoiced contrasts were chosen so that the participant attends to the stimuli throughout the task because of the lesser contrast. The durations of CV syllables/pa/,/ta/,/ka/,/ba/,/da/ and /ga/were 295 ms, 278 ms, 335 ms, 404 ms, 329 ms, and 460 ms, respectively. The auditory n-back tests were designed using these six CV syllables in Presentation software Version 18.0 (Neurobehavioral Systems Inc.,). The auditory n-back test comprised of the 1-back task and 2-back task. six CV syllables were presented randomly at 2000 ms inter-stimulus interval.[26,32-34] Each task had a total of 120 syllable trials presented randomly across each participant, of which 25% (30 trials) were target n-back trials. The random presentation of the syllables in a set was controlled by presentation software. All the stimuli were presented at their most comfortable loudness level.

Procedure

The participants in both AWS and AWNS group performed auditory 1- and 2-back tests. The cognitive load on the participant was higher in the 2-back task (more difficult) than the 1-back task. The tests were carried out using Presentation software Version 18 in a personal computer, and the responses were recorded in the same software. The stimuli were presented through Sennheiser HD 202 II headphones. Participants were made to sit in a comfortable chair and heard the series of syllables at their MCL. During the 1-back task, participants were instructed to press a button whenever they heard the same syllable as the one before [Figure 1]. Whereas during 2-back task, whenever the same syllable repeated again after a syllable, participants were supposed to press a button [Figure 1].

The measures obtained from the presentation software were reaction time (RT), accuracy, hits, misses, false alarms, and correct rejections. Hit rate was calculated by dividing hits by a sum of hits and misses. False alarm rate (FAR) was calculated by dividing false alarms by a sum of false alarms and correct rejections. By using hit rate and FAR, d prime (d') was calculated using d' calculator,[35] which is the difference between *z*-scores of hit rate and FAR. RT, accuracy, FAR, and d prime (d') for each participant in each n-back task was considered for further statistical analysis.

Results

The means of all the four parameters considered were compared between the two groups. Figure 2 shows the mean RT in AWNS and AWS obtained during 1- and 2-back tasks.

It can be noticed from Figure 2 that the mean RT was shorter for 1-back task when compared to 2-back task in both the groups. Further, when the mean RT was compared between AWS and AWNS during 1- and 2-back tasks, it was shorter in AWS than AWNS in both the tasks [Figure 2]. However, when a nonparametric Mann–Whitney U-test was applied, the difference between AWNS and AWS was not statistically significant for both 1-back ($z = -1.545$, $P = 0.136$) and 2-back tasks ($z = -1.28$, $P = 0.222$). From Figure 2, it can also be seen that the mean accuracy is 91.1% and 94% for 1-back task in AWNS and AWS respectively, which reduced to 66.67% and 56.33% during 2-back task in AWNS and AWS, respectively. Mann–Whitney U-test revealed no significant difference between the groups during 1-back task ($z = -0.788$, $P = 0.489$). Even though it can be seen from the Figure 2 that the mean accuracy for AWNS during 2-back task was higher when compared to AWS, there was no statistically significant difference observed on Mann–Whitney U-test ($z = -1.197$, $P = 0.258$). However, when the FAR was compared between the AWNS and AWS, there was a significant difference during 2-back task ($z = -2.437$, $P = 0.014$) but not during 1-back task ($z = -1.595$, $P = 0.136$). The mean FAR for 1- and 2-back tasks in AWS and AWNS can be seen in Figure 3.

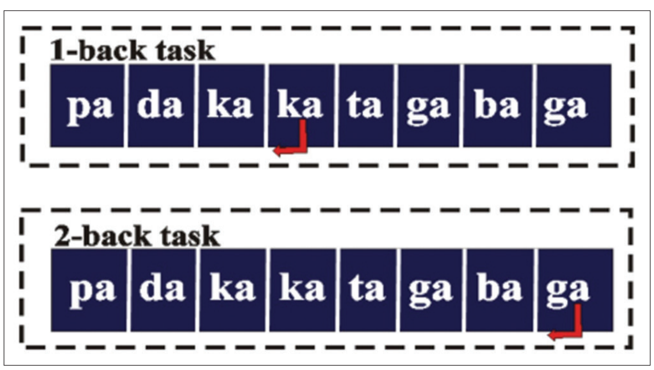

Figure 1: Representation of 1- and 2-back tasks. Note that auditory forms of the consonant-vowel syllables were actually presented

It can be noted from Figure 3 that the FAR was higher during 2-back task when compared to 1-back task in AWNS, but it was greater for 1-back task along with larger standard deviation (0.37) compared to 2-back task (0.13) in AWS. Figure 3 also shows the mean *d*' during 1-back and 2-back tasks in AWS and AWNS. The mean *d*' was higher for 1-back task than 2-back task irrespective of the group. When the groups were compared, even though it appeared higher for AWNS than AWS during both the tasks, Mann–Whitney U-test showed significance only during 2-back task ($z = -2.340$, $P = 0.019$) and did not show significance during 1-back task ($z = -0.268$, $P = 0.796$).

Discussion

The results showed increased RT and decreased accuracy during 2-back task when compared to 1-back task in both the groups. This suggests that as the task becomes more difficult, the performance of both the groups reduces. This is in accordance with the previous imaging studies done using n-back task which has found increased activation as and when the memory load was increased by increasing the "n" in healthy participants.[24-26] The behavioral outcomes of these imaging studies also indicate increased RT and reduced accuracy with greater load. However, all the studies have varied the memory load using visual n-back paradigms with either letters or fractals as stimulus. Even if the trend appears to be the same when comparing 1- and 2-back task in AWS group, the mean RT was actually lower in AWS than AWNS though not significant in both 1- and 2-back task. These results are in contradiction to the previous study where the RTs were longer in AWS compared to AWNS during letter recall working memory tasks, which was true irrespective of the difficulty.[9] This contradicting results might be either due to the phonological complexity involved in the letter recall tasks or increased anxiety while responding. However, a study by Subramanian and Yairi[36] have found shorter RT in AWS. However, they had used an emotional stroop task to tap the working memory, which cannot be completely generalized to our study. The shorter RTs in AWS can be viewed either positively or negatively when comparing with AWNS. On positive note, shorter RT suggests faster processing speed in AWS than AWNS. However, adversely, increased anxiety which has been documented in AWS[37-39] might have resulted

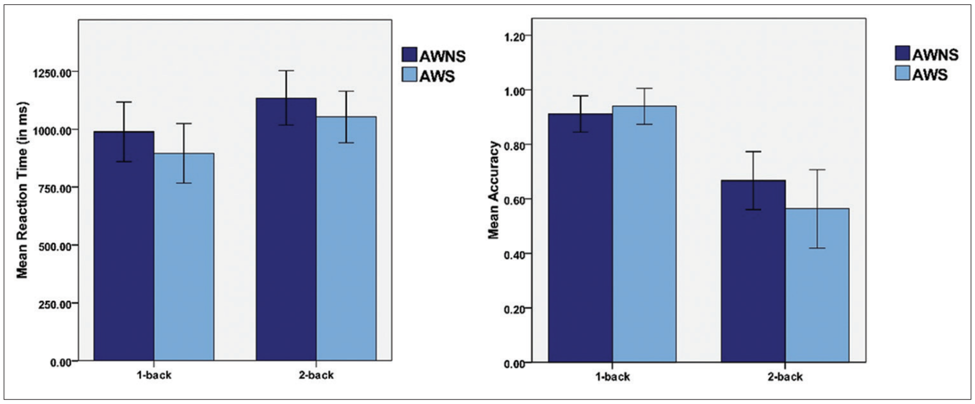

Figure 2: Mean reaction time (left) and mean accuracy (right) of who do not stutter and adults with stuttering during 1- and 2-back tasks (error bars represent 95% confidence interval of mean)

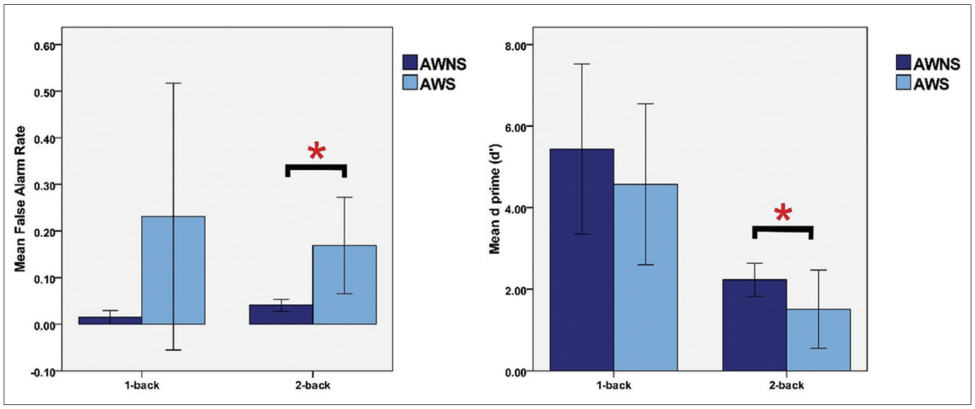

Figure 3: Mean false alarm rate (left) and mean d' (right) of who do not stutter and adults with stuttering during 1- and 2-back tasks (error bars represent 95% confidence intervals)

in shorter RT. Thus, to examine if it is because of anxiety or speed of processing, accuracy and false alarms might be of greater help. Another way to examine this query is to compare the activations in the brain areas during this tasks which is out of scope of the present study.

When the accuracy of responses was compared between both AWNS and AWS, there was no significant difference between the groups although visually it appeared lower in AWS than AWNS in 2-back task whereas for 1-back task it was almost similar in both the groups. The studies examining working memory performance in AWS earlier have considered accuracy as the main parameter in their analyses.[9,12,18] Jones *et al*.[9] found that the accuracy of letter recall decreased from three-letter string to five-letter string in both AWS and AWNS, which is in accordance with the present study. As the cognitive load increases both the groups find it difficult to cope up with the performance. A significant difference in accuracy scores between AWS and AWNS was also found during both three - and five -letter recall conditions.[9] The difference between AWS and AWNS was greater in 5-letter condition than the 3-letter condition. However, the present study did not show significant differences between AWS and AWNS. This might be because of the dual task condition used where the participant was needed to perform a rhyme judgement task simultaneously.[9] The rhyme judgment task involves phonological working memory where the study found a significant difference between AWS and AWNS during the most difficult rhyme condition.[9] The phonological memory was tapped in the previous studies using nonword repetition and phoneme elision tasks by varying the length of the syllables.[11,12] They showed poorer accuracy in AWS compared to AWNS in increased letter condition. This is comparable to the present study in terms of poorer performance when there is more demand. However, various other studies have found no differences between AWS and AWNS, either during working memory tasks[18] or phonological rhyme judgement task.[20] The focus was to compare the brain responses which were different between the groups rather than the behavioral correlates.[20] In Eichorn *et al*.,[18] the purpose was to compare the dysfluencies during the working memory task, so they used a simple task such that, the participants in both AWS and AWNS group get almost 100% accuracy in the baseline condition. None of the studies have exclusively tested working memory previously, and although there are mean differences, they are not significant statistically. Thus, considering only RT or accuracy to draw any differences between the groups might not be the best way to understand the differences between the two groups.

During 1-back task, even though the mean RT was lower and mean accuracy was higher in AWS, FAR was higher in AWS when compared to AWNS, though not statistically significant. The difference might not be significant because of the larger variability in the FAR shown as larger standard deviation in AWS. However, a statistically significant difference was found when FAR for 2-back task was examined. FAR was greater due to the increase in number of false alarms seen in AWS. The higher false alarms in AWS can be due to the increased anxiety during greater attentional demands (as the cognitive load increases) seen in AWS.[37-39] To some extent, this solves the dilemma of reduced RTs or higher accuracy (during 1-back) task which might be due to more number of false alarms that was noted in AWS. However, it may not be completely due to false alarms and cannot be generalized considering a single parameter. This result can be correlated though not exactly same, with the results obtained in a study examining phonological working memory where the number of attempts needed to produce the correct responses was calculated during four-syllable and seven-syllable nonword repetition and phoneme elision task.[12] The number of attempts made to produce the correct response was higher in AWS than in AWNS in both 4-syllable and 7-syllable condition whereas the significant difference in accuracy between AWS and AWNS was noted only during seven-syllable condition. Collectively, this suggests that measures such as RT or accuracy by may not provide clarity on subtle differences seen in AWS, but we should consider a composite measure or parameter like error rates too while comparing the groups to arrive at better inferences. Hence, *d* prime (d') was considered as it comprises of both hit rate and FAR to score an individual's response. However, *d*' was not significantly different between AWS and AWNS during 1-back task. Whereas during 2-back task, where it was more cognitively taxing, the *d*' was significantly different between AWS and AWNS. Thus, this suggests working memory deficits in AWS when the task is more cognitively demanding. When there is more demand, the working memory system in AWS tends to perform lower. When the situation becomes more demanding, there is depletion of the attentional resources which might show up as increased anxiety in AWS.[37-39] This increased anxiety makes them perform less accurately than their fluent counterparts. The other possibility for the lesser performance might be due to the poorer representation in the phonological loop.[20,21] Due to this, they might need extra attentional resources while performing any task. Collectively, the results obtained in the present study might be either due to the faulty phonological representations or attentional deficits that are found in persons with stuttering which reflect as working memory deficit or vice versa leading to a domino effect.

Limitations of the study

The limitation of the study is smaller sample size. Considering more number of participants might have led to clearer differences even in terms of RT and accuracy. Various other working memory tasks that are used in the previous studies could have been performed along with the n-back tests for better comparison. However, in most of the previous studies, working memory tasks served as one of the dual task where both groups had similar performance on working memory task. This was because the aim of those studies was to compare the dysfluencies or linguistic abilities while performing working memory tasks. Thus, even if we examined the performance on other working memory tasks, direct comparison with the previous studies may not have been appropriate.

Conclusion

The present study assessed phonological working memory by ruling out the influence of language abilities in AWS. Results revealed significant difference between two groups during 2-back task but performed equally well when it was 1-back task, which was less cognitively taxing. The *d*' was significantly different between AWS and AWNS in two-back task. This difference can be attributed to more number of false alarms seen in AWS, which might have resulted because of the anxiety in responding, compensating on attentional demands, which is in turn reflected as auditory working memory deficits during the difficult task. Whether it is anxiety or attentional resources that are contributing to the differences between the groups, can be examined through physiological responses during the working memory tasks, which can be the future implication of the study. Further, comparing the activations in the brain areas solely during the working memory tasks and when carrying out dual language-based tasks can provide inputs on the cortical networks that are distinct between the two groups. The present results provide preliminary evidence for auditory working memory deficits in persons who stutter. This can have implications to the sensory-motor deficits found in AWS, where the sensory input in terms of working memory can have an effect in the motor programming networks, which are interlinked.

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Conflicts of interest

There are no conflicts of interest.

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