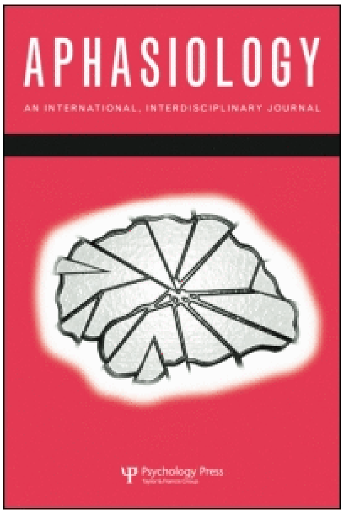

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# Verbal and non-verbal working memory in aphasia: What three *n*-back tasks reveal

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# Verbal and non-verbal working memory in aphasia: What three *n*-back tasks reveal

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*Background*: Researchers have found that many individuals with aphasia (IWA) present with cognitive deficits that may impact their communication, and perhaps underlie their language-processing deficits (e.g., Erickson et al., 1996; Murray et al., 1997; Wright et al., 2003). However, many investigations of cognitive ability in aphasia have included measures that may be considered "language heavy"; they require overt lexical, semantic, and/or phonological processing to follow the task instructions and/or formulate a response. Few have considered the amount of linguistic processing required to perform the task. Subsequently, it is not clear if poorer performance by IWA on cognitive tasks compared to neurologically intact (NI) participants is due to a deficit in the respective cognitive domain or due to the inability of IWA to perform the task because of their language difficulties.

*Aims*: The purpose of the current study was to explore the effect of varying linguistic processing demands in the context of a dynamic working memory task—an *n*-back task for participants with and without aphasia.

*Method & Procedures*: This study compared differences on three different *n*-back tasks within and across groups for individuals with aphasia and NI matched peers. Participants completed three different *n*-back tasks; stimuli for the tasks varied in "linguistic load". For each *n*-back task participants completed two levels of difficulty: 1-back and 2-back.

*Outcomes & Results*: The aphasia group performed significantly worse than the NI participants across the *n*-back tasks. All participants performed significantly better with the stimuli that carried a higher linguistic load (i.e., the fruit), than with the fribbles (semi-linguistic) and blocks (non-linguistic). All participants performed significantly better on the 1-back than the 2-back working memory task. Unlike the NI participants, IWA performed equally poorly with the fribbles and the blocks in the 2-back task.

*Conclusions*: Overall, the performance of individuals with aphasia on working memory tasks that varied in their linguistic load was similar to the control group but reduced. However, unlike the NI participants, IWA were less skilled at rapidly utilising linguistic knowledge to increase performance on the fribbles, demonstrating the further decrement in working memory that results from a decreased ability to utilise a linguistic strategy to increase performance on verbal working memory tasks. The results of this study indicate that language ability has a significant influence on performance on working memory tasks and should be considered when discussing cognitive deficits in aphasia.

***Keywords:*** Working memory; Aphasia; *n*-back.

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Performance by adults with aphasia on attention and working memory measures is receiving more attention in the literature. Researchers have found that many individuals with aphasia (IWA) present with cognitive deficits that may impact their communication, and perhaps underlie their language-processing deficits (e.g., Erickson, Goldinger, & LaPointe, 1996; Murray, Holland, & Beeson, 1997; Wright, Newhoff, Downey, & Austerman, 2003). However, many investigations of attention and memory ability in aphasia have included measures that may be considered "language heavy"; they require overt lexical, semantic, and/or phonological processing to follow the task instructions and/or formulate a response. Subsequently, interpretation of the results is limited. It is not clear if poorer performance by IWA on such cognitive tasks compared to NI participants is due to a deficit in the respective cognitive domain or due to the participants' inability to perform the task because of their language difficulties. It has been demonstrated with other populations that disassociations between cognitive and linguistic functions can exist. For example, some individuals with traumatic brain injuries (TBI) present with attention and memory impairments and have relatively preserved language ability (Hagen, 1981). However, it is unclear whether the dissociation is reversible; that is, whether an individual may present with impaired language ability, but relatively preserved attention and memory abilities.

It is well known that linguistic encoding, including phonological and rich semantic encoding, enhances recall of information on short-term memory tasks. Conrad and Hull (1964) demonstrated that short-term memory span is dependent on phonological encoding and subvocal rehearsal of visually presented items. When phonological access or rehearsal is blocked due to articulatory suppression, memory span for visually presented digits significantly decreases (Baddeley, Lewis, & Vallar, 1984).

In addition to phonological encoding, semantic encoding also has an effect on the ability to recall information. It has been well documented that memory is enhanced when information is semantically encoded (e.g., Intraub & Nicklos, 1985; Weldon & Roediger, 1987). For example, Hockley (2008) found that pairs of line drawings were better recalled than when the same pairs were presented verbally, suggesting that pictures receive more extensive semantic processing than words. Semantic information also influences attention, as demonstrated by the cocktail party effect (Moray, 1959). That is, when participants are presented relevant and irrelevant messages, one to each ear via headphones, and asked to attend to the relevant message, they are less able to inhibit the unattended message when it contains semantically meaningful information such as the participant's name (Moray, 1959).

There is a significant body of research demonstrating the linguistic influence on cognitive mechanisms. Craig and Lockhart's (1972) influential levels of processing hypothesis is based on research demonstrating that items processed purely in terms of their physical appearance are not retained as well as items that are verbalised. Further, items that are richly encoded in meaning are those that are best recalled (Baddeley, 2007). It is easily plausible to imagine a negative impact on memory and attention for IWA who may have difficulty accessing verbal and/or semantic representations. Sharing these concerns, Martin and Ayala (2004) cautioned researchers to specify the nature of the task when discussing verbal short-term memory (STM), particularly in IWA. She found a relationship among measures of lexical-semantic and phonological processing and different types of short-term memory tasks and concluded that verbal STM is not a unitary capacity that can be measured in isolation of language abilities.

Martin's measures included digit and word span tasks, and thus were isolated to the capacity of short-term memory. However, working memory takes into account not only storage capacity, but also attention and executive processes (Baddeley, 2007). Impaired performance on measures of working memory has been well documented in IWA (e.g., Caspari, Parkinson, LaPointe, & Katz, 1998; Friedmann & Gvion, 2003; Wright et al., 2003) but minimal consideration has been given to the amount of linguistic processing required to perform the tasks.

Wright, Downey, Gravier, Love, and Shapiro (2007) developed several *n*-back tasks to tap specialised working memory capacities by manipulating the stimulus type as well as the task. The *n*-back task appears ideal for measuring working memory; it requires participants to decide whether each stimulus in a sequence matches the one that appeared *n* items ago. It therefore requires temporary storage and manipulation of information, while constantly updating the contents in working memory (Jonides, Lauber, Awh, Satoshi, & Koeppe, 1997). The *n*-back task is particularly ideal for individuals with aphasia because it requires only a button press for the response. In addition the stimuli can be manipulated to investigate different processes while keeping the working memory load the same.

Although working memory ability in IWA has been extensively investigated in recent years, researchers have done little to consider the amount of linguistic processing required to perform the task. For example, Daneman and Carpenter's (1980) working memory measure, which has been modified and used with individuals with aphasia, requires syntactic, phonological, and semantic processing. It is unknown how participants with aphasia would perform if the linguistic load (see Method section for detailed discussion) of working memory tasks were manipulated. In order to understand the role language plays in working memory tasks, we need to compare the performance of IWA on comparable tasks that vary in their linguistic load.

The purpose of the current study was to explore the effect of varying linguistic processing demands in the context of a dynamic working memory task—an *n*-back task. We were particularly interested in whether IWA performed differently across stimuli that varied in their linguistic load, as well as in comparison to non-language-impaired participants. The *n*-back tasks included three different stimuli that varied in linguistic load. Assuming the working memory deficit in aphasia is specific to and dependent on language, it was hypothesised that individuals with aphasia would be impaired to a greater extent relative to control-matched peers with the *n*-back stimuli that carried a heavier linguistic load (fruit), than on the stimuli with a lighter linguistic load (fribbles). That is, we expected the NI participants to be able to better utilise semantic and phonological encoding on the linguistic and semi-linguistic stimuli than individuals with aphasia. We expected that all groups would have difficulty using a verbal strategy on the non-linguistic stimuli (blocks), therefore we expected no difference between the groups' performance on the blocks. In contrast, if the working memory deficit in aphasia were due to non-linguistic cognitive deficits such as attention or a generalised reduced memory capacity, we expected no interaction between groups, but expected the individuals with aphasia to be depressed in their performance compared with NI participants similarly across stimuli.

# METHOD

## Participants

Participants included 12 IWA and 12 neurologically intact (NI) people who were matched to the IWA by age and education. All participants with aphasia presented with unilateral left hemisphere damage subsequent to cerebrovascular accident. Clinical criteria for participation for individuals with aphasia included (a) presence of aphasia as indicated by performance on the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2006), (b) no history of dementia or other neurological deficits as indicated by self report, (c) at least 6 months post onset of stroke, (d) premorbid right handedness. Inclusion criteria for all participants included self-reported aided or unaided hearing within normal limits; aided or unaided visual acuity within normal limits as indicated by passing a vision screening (Beukelman & Mirenda, 1998); and sufficient dexterity control to make responses using a computer keyboard. NI adults had no history of neurological impairments as indicated by self-report and scores within normal limits on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). Demographic information is reported in Table 1.

## Stimuli and tasks

The *n*-back task was presented with three different types of stimuli that varied in their linguistic load. We operationally define "linguistic load" as the degree to which an object could rapidly elicit a consistent name in a confrontation naming task. The term "linguistic load" refers to the semantic and phonological graded differences that are present across the three different types of stimuli included in this study. It does not indicate difficulty level for stimulus types, but rather the ease with which participants can rapidly assign meaning and phonological form to the objects. The stimuli included *fruit*, which carried the greatest linguistic load (easiest to name); *fribbles*,

TABLE 1
Demographic information for the participant groups

| *Participant* | *Age* | *Level of education* | *Gender* | *Months post CVA* | *WAB-R AQ* | *WAB-R profile* |
|---|---|---|---|---|---|---|
| 1 | 65 | 14 | M | 58 | 76.3 | Conduction |
| 2 | 58 | 13.5 | M | 64 | 86.1 | Anomic |
| 3 | 73 | 12 | M | 39 | 85.2 | Anomic |
| 4 | 55 | 14 | M | 24 | 57.6 | Broca |
| 5 | 66 | 14 | F | 172 | 56.3 | Broca |
| 6 | 34 | 14 | F | 21 | 90.7 | Anomic |
| 7 | 38 | 14 | F | 141 | 57.7 | Broca |
| 8 | 62 | 18 | F | 84 | 61.3 | Broca |
| 9 | 72 | 12 | M | 57 | 64.9 | Anomic |
| 10 | 65 | 11 | F | 119 | 89.4 | Anomic |
| 11 | 65 | 14 | M | 58 | 54.4 | Broca |
| 12 | 76 | 14 | M | 16 | 47.9 | Broca |
| Mean | 60.8 | 13.7 | M = 7, | 70 | 68.82 | |
| (*SD*) | (12.5) | (1.64) | F = 5 | (46.95) | (15.66) | |
| Mean | 61 | 14.5 | M = 5 | N/A | N/A | Control Group |
| (*SD*) | (11.20) | (1.89) | F = 7 | | | |

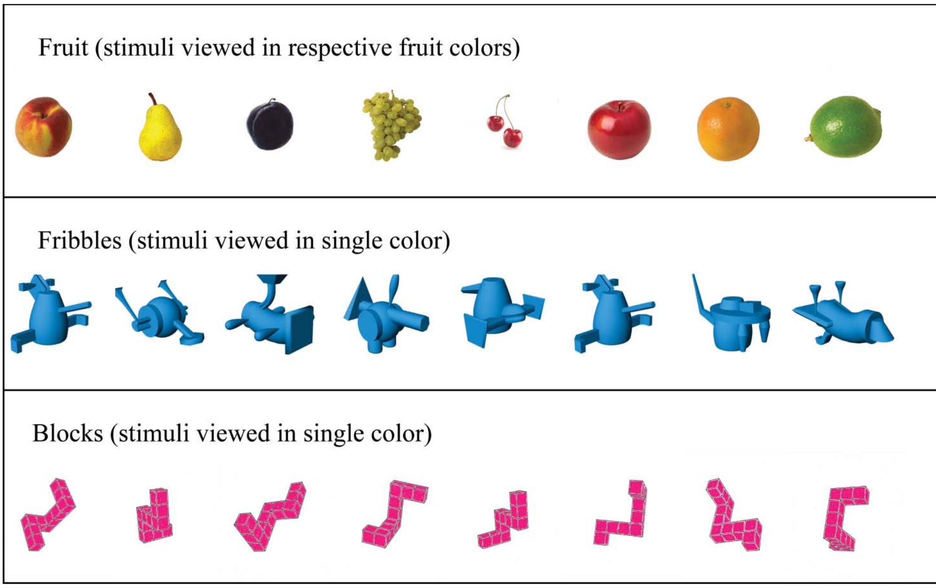


**Figure 1.** N-back task stimuli used to vary linguistic load. Fribble and block (Shepard & Metzler, 1977) stimuli courtesy of Michael J. Tarr, Brown University, http://www.tarrlab.org



which were novel objects and considered the semi-linguistic condition; and *blocks*, which were the non-linguistic stimuli. The fribbles were two-dimensional blue objects easily distinguishable from one another. The blocks were three-dimensional coloured cubes connected to one another in different arrays; they were selections from those used by Shepard and Metzler (1971) in their study of mental rotation. None of the blocks were mental rotations of one another. The fribbles and blocks were maximally distinct objects selected from those provided on the following website: http:// www.tarrlab.org/ Stimuli are presented in Figure 1. The fruit stimuli have the heaviest linguistic load because a participant can easily access the phonological form and semantic representation of the stimuli. The fribbles have less of a linguistic load, and the blocks were considered non-linguistic. To verify that the stimuli differed in their linguistic load, five neurologically intact participants viewed each fribble (and block) during task development. They were instructed to assign a name to the item. If participants were not able to generate a name within a reasonable amount of time (15 seconds) the next item was presented. Participants generated meaningful object names for the fribbles; however, there was little agreement across participants. Participants did not generate meaningful object names for the blocks, although some participants were able to come up with lengthy descriptions (e.g., "three blocks down with two across and pointing out").

All participants were administered the tasks at two levels of processing difficulty—1-back and 2-back. For the 1-back and 2-back conditions the participants responded with their non-dominant hand by pressing the spacebar on a keyboard when the current token was the same as the one *n* back. The non-dominant hand was used because some participants were unable to respond with their dominant hand due to hemiparesis. For all tasks, instructions were as follows, "*Push the spacebar when the object you just saw is the same as the one [n] back.*" A 0-back task was also administered to all participants to ensure they were able to reliably attend to the task and discriminate between objects. The 0-back level required a response when a specific token was presented (e.g., lime).

Each *n*-back task contained eight different stimuli. In the 1-back task there were 33 target items used for determining performance, and there were 32 targets in the 2-back task. All 1-back tasks included five blocks: one practice block of 10 items with 2 targets; a second block with 26 items and 8 targets; two blocks (blocks 3 and 5) with 24 items and 8 targets; and a fifth block (block 4) with 24 items and 9 targets. All 2-back tasks also consisted of five blocks: one practice block with 10 items and 2 targets; a second and fourth block with 26 stimuli and 8 targets; and a third and fifth block with 24 stimuli and 8 targets. The percentages of tokens that were targets in the 1-back and 2-back tasks were 33% and 32%, respectively. These percentages were selected to be consistent with *n*-back tasks in the literature while also falling within the ability level of the participants, to keep the tasks from being too frustratingly long.

## Experimental procedures

Assessment of participants with aphasia was completed prior to the experimental sessions. During the assessment phase informed consent was obtained, the WAB-R was administered, and vision screening was conducted. The NI participants completed the informed consent, vision, and cognitive screening measures, as well as other experimental tasks that were not related to this study, during their first session. All *n*-back tasks were administered in a second session in a quiet room in the university lab or at the participant's home. All participants were administered the 0-back followed by the 1-back and 2-back tasks. Presentation order for stimuli type was randomised across participants and tasks. Instructions were provided verbally and using paper illustrations prior to each task (0-back, 1-back, 2-back). Instructions were repeated until participants demonstrated understanding by pointing to correct stimuli on the printed sample illustrations. Participants also completed practice items on the computer that were identical to the experimental task. Computer practice items were administered prior to each task for each stimuli type. After completion of the experimental tasks, participants answered open-ended questions regarding their thoughts about the experiment and whether certain tasks or stimuli were easier than others. Additionally, participants completed a confrontation naming task with all stimuli used in the experiment and responses were recorded.

Stimuli were presented using E-prime software with a 3500 ms stimulus onset asynchrony (SOA). The stimulus was presented for 750 ms and the interstimulus interval between tokens was 2750 ms. Accuracy and response times (RT) were recorded by the stimulus presentation software with millisecond precision. Because participants were not specifically instructed to respond with any rapidity—only "quickly, as another item will be coming up soon"—RTs were not viewed as an index of processing time and were not subjected to statistical analyses. Response accuracy, in the form of hit rates and false recognition rates, was recorded and converted to d' values and then subjected to statistical analyses. Signal detection theory advocates for the use of d' as a bias free measure of internal response or sensitivity (Lachman, Lachman, & Butterfield, 1979). D' is valuable because it does not depend on the criterion the participant is adopting. That is, it accounts for the individual's tendency to respond liberally, or in other cases conservatively, in the presence of a signal. D' is calculated by subtracting the *z*-scored false positive rate from the *z*-scored hit rate.

## RESULTS

A mixed analysis of variance (ANOVA) was performed with group as the between-participants factor. The two within-participants factors included stimulus type (fruit, fribbles, or blocks) and working memory load (1-back or 2-back). Descriptive statistics are reported in Table 2. Results of the mixed ANOVA revealed a significant group main effect, $F(1, 22) = 9.28$ $p < .01$. The aphasia group had significantly lower d' values compared to the NI group. As expected, there was a significant working memory load main effect within groups, $F(2, 22) = 137.72$, $p < .01$ with d' values for the 1-back being significantly higher than the 2-back. There was also a significant main effect for stimulus type, $F(2, 21) = 24.054$, $p < .001$. Finally, a significant interaction between working memory load and stimulus type was present, $F(2, 21) = 7.51$, $p < .01$. To explore the effect of stimulus type across groups, paired sample $t$ tests controlling for multiple comparisons using Holm's (1979) sequential Bonferroni approach were conducted. Fruit had significantly higher d' values than fribbles, $t(23) = 5.15$, $p < .001$, and blocks, $t(23) = 7.23$, $p < .001$. The d' values for fribbles were also significantly higher compared to d' values for blocks, $t(23) = 3.01$, $p < .01$. Additional analyses to explore the significant interaction revealed that the differences across stimuli types were greater in the 2-back than the 1-back conditions for the comparison between the fruit and fribbles, $t(23) = 3.089$, $p < .01$, and between the fruit and blocks, $t(23) = 3.681$, $p < .01$. There was no significant difference between the fribbles and blocks across the different working memory loads, $t(23) = 1.169$, $p = .26$. No other interaction was significant.

### Aphasia group

Of particular interest was the pattern of performance across the different stimuli types within groups. To explore within-group differences the simple main effects for the aphasia group and the control group adjusting for the multiple comparisons using Holm's sequential Bonferroni approach were analysed. A repeated-measures

TABLE 2
Descriptive statistics for d′ scores on 1-back and 2-back tasks with different stimuli

| *Task* | *Group* | *M* | *SD* |
|---|---|---|---|
| *1-back* | | | |
| Fruit | Aphasia | 3.23 | .91 |
| | Control | 4.12 | .41 |
| Fribbles | Aphasia | 3.03 | .95 |
| | Control | 3.86 | .53 |
| Blocks | Aphasia | 2.78 | 1.29 |
| | Control | 3.84 | .71 |
| *2-back* | | | |
| Fruit | Aphasia | 1.82 | .85 |
| | Control | 2.55 | .78 |
| Fribbles | Aphasia | 1.09 | .81 |
| | Control | 1.85 | .95 |
| Blocks | Aphasia | 0.86 | .70 |
| | Control | 1.37 | .77 |

$N = 12$.

ANOVA was conducted for the 1-back task with stimulus type (fruit, fribbles, blocks) as the factor. Results indicated no significant differences among stimuli for the aphasia group, $F(2, 10) = 1.12$, $p = .37$. A repeated-measures ANOVA for the 2-back with stimulus type as the factor was also performed. There was a significant main effect for stimulus type in the 2-back, $F(2, 10) = 25.64$, $p < .001$. Planned comparisons indicated the group performed better, with significantly higher d' values, on fruit than fribbles, $t(11) = 3.88$, $p < .01$, and blocks, $t(11) = 6.69$, $p < .001$.

Finally, to explore the relationship between overall language severity and *n*-back performance, a correlation analysis was conducted between WAB-R aphasia quotient (AQ) and the 1- and 2-back tasks for all stimuli. None of the comparisons were statistically significant.

### Neurologically intact group

Similar analyses as performed with the aphasia group were performed with the NI group to determine within-group differences across stimuli type. A repeated-measures ANOVA with stimulus type as the factor revealed significant differences among the stimuli in the 1-back task, $F(2, 10) = 6.36$, $p < .05$. Pairwise comparisons were conducted adjusting for familywise error rate using Holm's sequential Bonferroni approach. Results revealed significant differences between the fruit and fribbles, $t(11) = 3.49$, $p < .01$, but no significant differences between the fruit and blocks, $t(11) = 2.47$, $p = .03$ or the fribbles and blocks, $t(11) = .22$, $p =.83$ were found.

In the 2-back task there was a significant main effect for stimulus type, $F(2, 10) = 23.58$, $p < .001$. Significant differences were found among all stimuli in the 2-back task with fruit having significantly higher d' values than fribbles, $t(11) = 3.12$, $p < .05$, and blocks, $t(11) = 6.77$, $p < .001$; and fribbles having significantly higher d' values than blocks, $t(11) = 3.05$, $p < .05$.

## DISCUSSION

In this study we investigated working memory ability in individuals with and without aphasia. The participants with aphasia performed worse than their NI peers across the working memory measures that varied in linguistic load. The lack of a group interaction demonstrates that the participants with aphasia performed similarly to the NI participants, but with less accuracy across all stimuli. Thus, it appeared that the poorer performance of IWA on the working memory tasks was not solely a result of their language impairment. These results appear to support previous literature indicating that IWA have additional cognitive deficits that may be independent of language (e.g., Erickson et al., 1996; Hula & McNeil, 2008; Tseng, McNeil, & Milenkovic, 1993). Further investigation is warranted to better understand the relationship between cognitive and linguistic deficits in IWA.

Across the three *n*-back task stimuli, both groups performed significantly worse on the 2-back compared to the 1-back tasks. These results are consistent with previous findings indicating that processing load is increased as the number of stimuli to be recalled increases (Jonides et al., 1997; Wright et al., 2007). For the aphasia group, no significant differences were found among stimuli for the 1-back task. However, a significant difference was found for the NI group between the fruit and fribbles *n*-back tasks. The NI group performed significantly better on the 1-back when fruit were the stimuli compared to the fribbles. This was likely a result of the limited within-group variability for these stimuli and may not be particularly meaningful given the relatively high performance of the NI participants on all 1-back tasks (see Table 2). Of interest is how the participant groups performed across the different 2-back tasks.

## NI Participants

In the current study the NI participants performed best on the *n*-back task with fruit stimuli, in comparison to the fribble stimuli; they performed the worst on the task with the block stimuli. Their performance was similar to findings from previous investigations, but with short-term memory (STM) tasks, where the linguistic nature (load) of the stimuli was manipulated (e.g., Baddeley et al., 1984; Conrad & Hull, 1964; Hockley 2008; Intraub & Nicklos, 1985; Weldon & Roediger, 1987). The use of verbal and semantic encoding improves object recall; as linguistic load declines and stimuli are not able to be verbally or semantically encoded easily, then performance declines.

Relatedly, findings from the change-detection literature are relevant for interpreting the results. Change blindness is a phenomenon reported in the visual perception literature, when participants fail to notice overt changes to objects, scenes, or other visual stimuli. For example, Simmons (1996) found that participants were unskilled at detecting changes to objects that were central to a visual scene, even when directly cued to look for such changes. Based on his research, Simons concluded that we are unable to retain information about objects' properties in the absence of verbal encoding. Applying these findings to the current study, possibly the NI participants were unable to accurately recall the blocks because they could not verbally encode the block stimuli.

## Aphasia group

The aphasia group performed differently across the 2-back tasks when the stimuli were manipulated. As the linguistic load declined across stimuli, so did the aphasia participants' task performance. Similar to their age-matched peers, the participants with aphasia performed significantly better on the fruit task compared to the fribbles and blocks tasks. However, no significant difference was found for the aphasia group's performance on the fribbles compared to the block stimuli. One possible explanation for the results is that, similar to the NI participants' performance with the blocks, the participants with aphasia could not easily verbally or semantically encode the stimuli. That is, phonological and/or semantic access was inadequate. According to Baddeley (2007), access to the phonological loop may be unavailable if visual stimuli cannot be converted to images with semantic, and hence phonological, representations, or if participants are blocked from converting semantic representations into phonological codes as is the case during articulatory suppression. After the tasks were completed, several IWA reported that the fribbles reminded them of known objects, but when probed further they were often able to describe, but not verbalise, an object name. In contrast, they were able to recognise and name the fruit. Possibly, the poorer performance by the IWA on the fribbles task compared to the fruit task may be due to their difficulty with rapidly assigning a name to the object that they could subsequently rehearse. Alternatively, it is possible that the participants with aphasia had particular difficulty with the fribbles, not because they were unable to access semantic and phonological information, but that they were unable to do so in a timely manner. The *n*-back task is a timed task that requires a rapid response (3500 ms SOA). To further explore these possibilities, future investigations could include *n*-back tasks where the interstimulus interval is manipulated.

The lack of a correlation between WAB-R AQ and the cognitively demanding *n*-back tasks was interesting, but not entirely surprising. Successful performance on the *n*-back task requires rapid storage and manipulation of semantic and phonological information. The lack of a correlation may be because the WAB-R AQ represents general language function and is not sensitive to the specific phonological and semantic processing demanded by the *n*-back working memory tasks, nor to the additional cognitive demands inherent in the *n*-back task. Additional investigation is warranted to resolve these issues.



## Conclusion

These results demonstrate that working memory is greatly enhanced by verbal encoding, particularly for IWA. Overall, the performance of individuals with aphasia on working memory tasks that varied in their linguistic load was similar to the control group but reduced. However, unlike the NI participants, IWA were less skilled at rapidly utilising linguistic knowledge to increase performance on the fribbles, demonstrating the further decrement in working memory that results from a decreased ability to utilise a linguistic strategy to increase performance on verbal working memory tasks. The results of this study indicate that language ability has a significant influence on working memory performance. Although these findings cannot be generalised to individuals with more severe aphasia, it is apparent that researchers and clinicians interested in cognitive performance in IWA should carefully consider the extent to which language processes influence cognitive function.

Due to the multi-component nature of the *n*-back task, we were unable to distinguish between deficits resulting from a reduced storage capacity and deficits resulting from a more central executive deficit in the ability to rapidly shift attention in order to drop and update the relevant information. Future research should incorporate attention and short-term memory span measures in conjunction with the working memory tasks in order to tease out the primary deficit contributing to the working memory deficits in IWA. In addition, thorough lexical-semantic and phonological testing of individual participants will enable a more concise understanding of the role of phonological and semantic encoding on the working memory process in IWA. Using such measures in combination with cognitive tasks would allow a more precise understanding of the impact of language ability on cognitive task performance.

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