Investigating distinct semantic processing ability in individuals with Dementia using n-back task

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Submission date: 03-Jul-2020 03:31PM (UTC+0530)
Submission ID: 1352970617
File name: 1215-Article_Text-1747-1-2-20200703.doc (1.8M)
Word count: 5343
Character count: 30841

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Abstract

Encoding, storing, and manipulating information in working memory is critical for perception as well as cognition. Working memory is crucial in the processing of any linguistic stimuli. Assessment of working memory is fundamental in any evaluation of cognitive abilities. The decline in working memory has been reported in normal as well as pathological aging. This study investigated the distinct semantic processing ability through a working memory task (n-back) and the effect of various stimuli categories on working memory in ten neurotypical individuals and seven individuals with Dementia. The findings of this study revealed that individuals with Dementia significantly differ in their working memory capacity when compared to neurotypical individuals. This could be due to the impaired ability to access semantic information and slow processing speed. Differences were also found concerning the processing of various stimuli categories within both the study groups. These differences are attributed to the varied processing load put forth by different stimuli within the working memory and to some extrinsic factors such as familiarity with the stimulus. The study evidences the importance of objective working memory assessment in differentiating individuals with dementia and neurotypical individuals.

***Keywords**: n-back, Linguistic Processing, Dementia, Semantics*

Background

Working Memory (WM) is the limited-capacity storage system involved in the maintenance and manipulation of information over short periods of time (Baddeley, 1986). This working memory is an executive function that involves holding information and working within the mind. Therefore for the executive processing to happen, the linguistic aspects, the attention, and the WM are often conceptualized as a resource pool (Just & Carpenter, 1992). Concerning the linguistic aspects, the comprehension and functional use of language require cognitive processes such as retrieval, information processing, maintaining, and interpreting information or representations (Martin & Reilly, 2012); which is a part of WM. Thus, various cognitive tasks like verbal reasoning skills, learning ability, mathematics, and language processing are related to working memory (Conway et al., 2005).

The WM stores and updates appropriate information to aid goal-directed behavior (Gajewski et al., 2018). Its span tasks measure a fundamental capacity of the individual and are central to any assessment of cognitive abilities (Lépine et al., 2005). For example, the n-back task of WM assessment assesses memory components and the ability to process the memorized component simultaneously. There is a variant form of this "n-back" procedure (Gevins & Cutillo, 1993) which is employed with human studies. The participants had to monitor a series of stimuli and had to respond whenever a stimulus is presented that is the same as the one presented 'n' trials previously, where 'n' is a pre-specified integer, usually 1, 2, or 3. This task requires on-line monitoring, updating, and manipulation of remembered information and is assumed to place great demands on several key processes within working memory.

The stimuli for this n-back task can be from various input modalities like visuo-spatial, auditory, and olfactory which create demands on different processing systems. Also,

the manner of stimuli presentation could be verbal stimuli (e.g., letters and words) and non-verbal stimuli (e.g., shapes, faces, and pictures) along with the type of monitoring that is required for any n-back task (e.g., the identity of the same face) is also important. Finally, concerning the working memory load, it is often varied up to 3-back even though the validation of results with respect to the poor performance of some individuals is reported (Callicott et al., 1999) and the 0-back condition does not require the manipulation of information within working memory. Despite the huge amount of review; however, there is little agreement on various issues pertaining to the assessment of WM in individuals with Dementia. The issues are, (1). The consecutive presentation of stimuli, each requiring a decision of matching with previous or the second to last, etc, (2). Use of a single probe stimulus requiring a decision to say whether the probe was part of a set of multiple stimuli. (3). Delayed simple matching tasks are the presentation of a single stimulus that should be compared to a second, subsequently presented one.

However, the recent review suggests the use of lexical categories at word level assessing semantics and at sentence level assessing syntactic aspects as a stimulus to measure a person's working memory capacity. This task was developed by Kirchner (1958) and is a continuous performance task that helps in assessing a part of working memory and its capacity. Therefore, to assess WM capacity in individuals with dementia, an n-back task with different types of stimulus either linguistic or non-linguistic may be suitable and suitably used one.

The additional information is that numerous cognitive functions are relevant to the n-back task with the impression of the dorsolateral frontal cortex (approximately Brodmann areas 9/45) being responsible for certain functions. To list a few are, holding spatial information on-line, monitoring and manipulation within WM, response selection, memory

facilitated by the implementation of strategies, organization of material before encoding and verification and evaluation of representations that have been retrieved from long-term memory. Regarding mid-ventrolateral frontal cortex (Brodmann areas 45,47), the distinct set of cognitive processes that is relevant to the n-back task is the selection, comparison and judgment of stimuli held in short-term and long-term memory, holding nonspatial information on-line, stimulus selection, the specification of retrieval cues and elaborated encoding of information into episodic memory. The other cognitive function like stimulus-response mapping or the buffer for perceptual attributes and storage of working memory content is related to the parietal lobe. The error detection and response correction in relation to increased effort, complexity, or attention involved in a cognitive task is controlled by the anterior cingulate cortex.

Working memory decline is often accompanied with aging (Salthouse, 2015). Pathological aging observed in Dementia or Mild Cognitive Impairment (MCI) will show a much faster decline compared to normal aging or senescence. It is estimated that nearly 35.6 million persons worldwide were living with dementia in 2010 (Prince et al., 2013). The neuro-pathophysiology in terms of neuronal loss is especially marked in the medial temporal lobe, the hippocampus, and the entorhinal cortex/medial temporal cortex (Daulatzai, 2015), parietal lobe, and the parts of the frontal cortex and cingulated gyrus (Wenk, 2003). Eventually, this atrophy spreads through the cortex and encompasses the association cortices of the temporal, parietal, and frontal lobes.

Dementia is often characterized by a progressive reduction in memory and/or other cognitive processes including WM (Bragin et al., 2015). Virtually all kinds of dementia show WM deficits (Huntley & Howard, 2010; Iachini et al., 2009; Maestú et al., 2011). The subjective complaints of cognitive skills that are not captured by most Dementia assessment

tests are recognized and appreciated by experienced speech-language pathologists. However, few kinds of research are required to characterize the difficulties they report. There are very fewer procedures that are clinically feasible in identifying the underlying impairments or objectively validating the complaints of individuals with dementia. The majority of dementia research typically focuses on more typical long term memory loss as a hallmark for dementia along with poor scores on tests of inhibition (Simone & Baylis, 1997), to some extent the forward and backward digit span under working memory impairment. In contrast, evidence-based evaluative resources for different types of dementia resulting from particular pathophysiology affecting specific components of the language processing system (e.g., in Alzheimer's Dementia the semantic memory is affected) as well as impacting working memory is limited.

To date, numerous functional neuroimaging studies have addressed neural activation patterns associated with WM functions. The n-back task has face validity as a WM task as it requires maintaining, continuous updating, and processing of information. It has a moderate to good correlation with other measures such as Stroop task, measures of fluid intelligence, and measures of short term memory (Gajewski et al., 2018). However, there are already a few experimental approaches to examine the neural correlates of WM. The diversity was further enhanced by less common paradigms as well as the fact that researchers employ a various variety of stimuli (e.g., verbal material, natural objects, or abstract symbols) and various additional experimental manipulations (e.g., varying load, retention interval or distraction). Hence, in the present study, an attempt is made to use varied semantic categories chosen under linguistic processing to assess the n-back threshold of individuals with dementia in comparison with neuro-typical.

Need for the study

In the recent past, WM has been investigated in individuals with aphasia using distinct n-back tasks (Deepa & Hema, 2019; Korani & Hema, 2019). These studies revealed significant differences across individuals with normal aging and individuals with aphasia and have upheld the possibility of an association between WM and linguistic processing ability in individuals with aphasia. With reference to the dementia population, the initial phases of dementia manifest with executive dysfunction and WM impairments along with episodic memory deficits (Kirova et al., 2015) need an assessment with distinct linguistic stimuli. The cognitive deficits that arise during MCI and manifest as a sign of advancement to dementia have to be assessed at cognitive, linguistic process level, or the combination of cognitive-linguistic processing level of working memory assessment.

Given that individuals with MCI/dementia have an early and progressive reduction in working memory, the use of an objective computerized task for early detection of cognitive-linguistic changes may aid in faster recognition of MCI and/or dementia (Fleming & Harris, 2008; Harris et al., 2008). This task is an attempt to evaluate the task performance which requires suppression of interference from a combination of internal sources (e.g., response tendencies or associations) and external sources (e.g., salient stimuli). This objective assessment will assess the ability to selectively attend to task-relevant information, and suppress interference from distracters, which is the central objective to carry out this task of sem-back that would evaluate the deficits in inhibitory ability of any individuals or their short term memory deficits. Hence the present study was planned.

Aim & Objectives

The present study aimed to assess working memory capacity and its effect on linguistic processing ability in adults with and without dementia using the n-back task. The objectives of the study were; (1) To examine the working memory capacity in

individuals with dementia and age-matched neuro-typical adults in the n-back task using E-Prime software; and (2) To study the effect of working memory abilities in processing distinct linguistic information (semantic) in the n-back task using E-Prime software.

Materials and Methods

Participants:

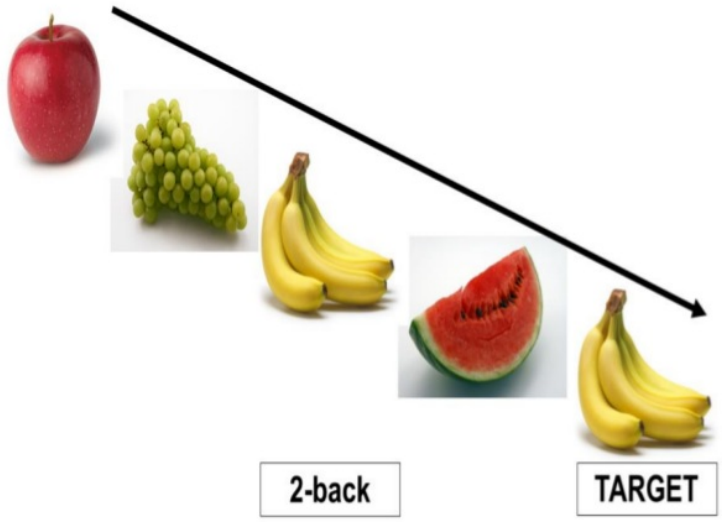
Participants considered were seven individuals with Dementia (IWD) under clinical group (Mean age of 77.4±5.2 years) and ten neuro-typical individuals (NTI) (Mean age of 71.9±7.3 years) matched to the clinical group based on age, gender, and education forming the control group. Informed consent was taken from the participants or their caretakers regarding the study. All participants demonstrated hearing and visual acuity to the normal limit on screening. IWD was diagnosed as having dementia by a neurologist and was evaluated by a Speech-Language Pathologist using the Kannada version of Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) and Clinical Dementia Rating Scale (CDR)(Morris, 1993). All the IWD were having a severity of very mild to mild dementia as per CDR Scale.

Stimulus:

With reference to the study of Wright et al., (2007), the sem-back task was created, which replicated the n-back using lexical items as the stimuli (Figure 1). These semantic lexical categories were lexical items like 'common objects,' 'fruits' and 'vehicles,' 'alphabets,' and 'single digits' considered as stimuli and termed this task as Sem-back task. These stimuli were obtained from the Kannada version of Western Aphasia Battery (WAB-K)(Shyamala & Kumar, 2008). Each category contained ten stimuli, which were randomly arranged to form the sequence for 1-back, 2-back, 3-back, and 4-back tasks.

Figure 1. An example of 2-back using lexical item

fruits



Procedure:

Participants of the study were seated comfortably in front of the computer screen and were instructed about the n-back task and were given a trial before the actual experiment, using a different set of stimuli. The experiment was programmed and ran using E-Prime Professional software (version 2.0) (Psychology Software Tools, Pennsylvania, USA) on an HP Notebook-15-ac101tu laptop. Within E-Prime, E-Studio and E-Data Aid modules were used to design the sequence of presentation of the stimulus with a fixed duration (2000ms), inter-stimulus interval with a fixed duration (1500ms) and participants response time with a fixed duration (5000ms) for both dementia population and neuro-typical individuals. The

training and the testing stimuli were presented at the center of fixation to the computer screen following one initial trial. For example, initially, the '+' sign was presented, and the participants had to focus at the center of the screen and followed by a lexical item presentation. This was mainly done to make the participants more vigilant and prepare for the actual task. To indicate their response, participants had to press, number keys 'one' or 'two' on a standard US keyboard; with 'one' for a match between test and target stimuli at sequential n^{th}–back (Example of paradigm considered for the present study was: 1-back, 2-back, 3-back, 4-back) and 'two' for a no-match. Responses delayed with no attempts of response till 5000ms by IWD were considered as 'no response,' and the next trial would begin. For every n-back, five trials were used, of which three were test trials, and two were catch trials in a random order of presentation to achieve a good construct validity of the Sem-back test.

Analysis:

Correct responses for a minimum of three trials within every level of the n-back task determined the level/threshold/accuracy of responses for the participants' sem-back task. The reaction time (RT) (in ms) and accuracy of responses were extracted using the E-Data Aid module within E-Prime 2.0 and were imported into Statistical Package for Social Sciences (SPSS Version 20) (IBM Corporation, New York, USA) for data analysis.

Results

Descriptive Statistics:

Following the administration of the 1-back, 2-back, 3-back, and 4-back tasks, the mean value for each of these Sem-back was obtained by taking an average of three trials. Subsequent to this average of all the levels were taken to calculate the total mean value for Sem-back. The mean and standard deviation (SD) of Sem-back tasks (1-back, 2-back, 3-back,

and 4-back) with reference to the RT (in ms) for the lexical category 'fruits', 'vehicles', 'common object', 'alphabets' and 'numbers' were obtained for IWD and NTI using descriptive statistics and the results are shown in Table 1.

Table 1: Results of descriptive statistics of RT for Sem-back task of individuals with Dementia and neuro-typical individuals

Working memory tasks Sem- Back tasks	**Groups**			
	Individuals with Dementia		**Neuro-typical Adults**	
	Mean (ms)	**SD**	**Mean (ms)**	**SD**
1. Lexical category 'Fruits'				
Sem1- Back	4132	87	1742	137
Sem2- Back	4555	310	1980	343
Sem3- Back	4379	305	2073	353
Sem4- Back	NR*	NR	2709	316
2. Lexical category 'Vehicles'				
Sem1- Back	3537	410	1546	149
Sem2- Back	3529	474	2129	367
Sem3- Back	3627	557	2302	308
Sem4- Back	NR	NR	2949	469
3. Lexical category 'Common Objects'				
Sem1- Back	4423	500	1527	163
Sem2- Back	4170	527	1833	268
Sem3- Back	NR	NR	2140	298
Sem4- Back	NR	NR	2859	433
4. 'Alphabets'				
Sem1- Back	3395	628	1463	187
Sem2- Back	3796	129	1782	143
Sem3- Back	4210	616	2361	423
Sem4- Back	4368	537	2790	393
5. 'Numbers'				
Sem1- Back	2723	225	1486	154
Sem2- Back	4274	437	2074	343
Sem3- Back	4182	510	2475	412
Sem4- Back	NR	NR	3009	539

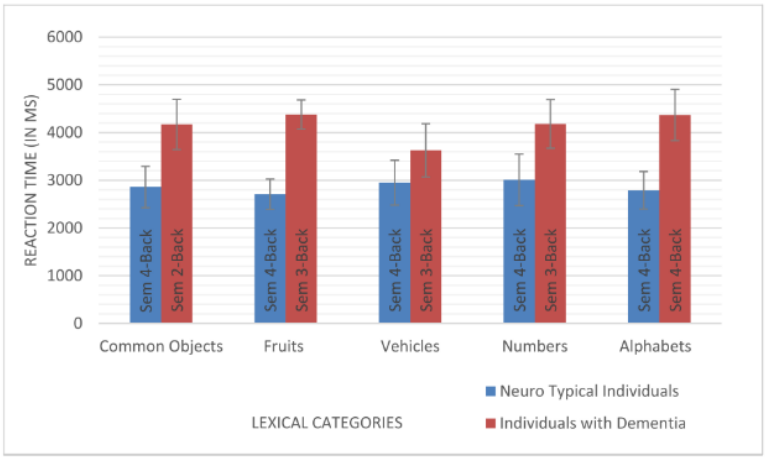
* NR- No Response; Individuals with Dementia (n=7); Neuro-typical Adults (n=10).

From Table.1, it can be observed that the mean RT (ms) or the time taken to execute Sem-back tasks by IWD was greater compared to NTI for all the semantic categories. Also, the standard deviation of both the groups of participants across all levels of the sem-back task was observed to be less than half of the mean value. Further, an increase in RT was demonstrated by both the groups in the present study as the task became more and more

complex (levels of 'n' increased). Thus, the performance of IWD and NTI was analyzed with reference to RT.

The additional observation was that the performances of IWD with respect to the level/threshold/accuracy of responses were scattered. IWD demonstrated a threshold of 4-back for 'alphabets,' 3-back for 'numbers,' lexical category 'fruits' and 'vehicles,' and 2-back for lexical category 'common objects.' However, NTI was able to perform until 4-back level for all categories of semantic stimuli with a constant threshold for all the category and IWD was able to perform at 2-back, 3-back, and 4-back with a very scattered threshold. However, Figure 2 depicts the Mean RT at the above-mentioned threshold level for NTI as well as IWD. It is observed that even though the threshold for 'alphabets' is 4-back for IWD and NTI, there was a difference in their RT.

Figure 2. Mean reaction time for various semantic categories with respect to specific threshold obtained by Individual with Dementia and Neurotypical individuals



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Comparison of linguistic processing n-back tasks performance between IWD and NTI groups:

Mann Whitney-U test was administered (with reference to RT) to examine the differences in linguistic processing on the n-back tasks between IWD and NTI groups. It was revealed that the performance of IWD and NTI groups at all their threshold levels of the sem-back task were significantly different (/Z/ values ranging from 2.278 to 3.416; $p < 0.05$). Results of the Mann Whitney-U test at the different lexical categories with their respective threshold levels for IWD and NTI groups are tabulated in Table 2.

Table 2. Results of Mann Whitney U-test at lexical category and the respective threshold level for Neurotypical Individuals and Individuals with Dementia

Lexical Category	Threshold for NTI	Threshold for IWD	/Z/ value	*P*-Value*
Common Objects	Sem4- Back	Sem2- Back	3.25	0.00
Fruits	Sem4- Back	Sem3- Back	3.42	0.00
Vehicles	Sem4- Back	Sem3- Back	2.28	0.02
Numbers	Sem4- Back	Sem3- Back	3.06	0.00
Alphabets	Sem4- Back	Sem4- Back	3.25	0.00

*Significant difference across both the groups ($p < 0.05$) for all the categories

Comparison of linguistic processing at semantic categories within each group:

Friedman's test was administered (with reference to RT) to examine the differences in linguistic processing of semantic categories (lexical category 'fruits', 'vehicles', 'common object', 'alphabets' and 'numbers') on the sem-back tasks across these different semantic stimuli within IWD and NTI groups. The results of the within-group comparison are tabulated in Table 3.

Table 3. Results of Friedman's test for Neurotypical Individuals and Individuals with Dementia

Group	Neurotypical Individuals		Individuals with Dementia	
	Chi-square value	*P*-Value	Chi-square value	*P*-Value
Sem1- Back	12.40	0.015*	19.09	0.001$
Sem2- Back	9.36	0.053	8.80	0.066
Sem3- Back	11.04	0.026*	5.70	0.127
Sem4- Back	3.44	0.487	CNT^	CNT^

*Significant ($p < 0.05$) for Sem1-back and Sem3-back; $Significant ($p < 0.05$) for Sem1-back; ^Could not test due to lack of groups

The results of Table 3 revealed that there was significant differences exist between the categories of stimuli for both IWD and NTI groups at the 1-back level and NTI group at the 3-back level. Further, Wilcoxon signed ranks test was carried out to identify the differences between the groups, which revealed significant differences ($p < 0.05$) across the lexical categories and numbers and alphabets at a 1-back level for both NTI and IWD groups and at a 3-back level for NTI group. It is worth noting that significant differences were not observed across the lexical categories *viz*, 'fruits,' 'vehicles,' and 'common objects.'

Discussion

The standard group comparison was done between IWD and age-matched NTI aimed to assess the working memory capacity and its effect on linguistic processing ability using the n-back task. The major finding of the study was that IWD had poorer working memory capacity as revealed by the n-back threshold compared to NTI and the increased RT was taken by the IWD compared to NTI while executing the n-back task at different semantic categories. The statistically significant difference and the substantial difference in the thresholds and RT of both the groups in the present study could be because of the semantic memory impairments and impaired ability to access semantic information hypothesized as WM deficits in some patients with AD (e.g., on the reading span task) and requiring different processing load for different semantic categories (Bragin et al., 2015; Grossman et al., 1996; Kensinger et al., 2003). To add on, the functions of the visuospatial sketchpad, the episodic buffer, as well as a central executive, is impaired in IWD, according to Huntley & Howard (2010).

The evaluation of raw scores in terms of RT measurement, IWD required longer processing time to access and retrieve information from WM for all the categories of stimuli that were considered. According to the Processing-Speed Theory (Salthouse, 1996),

"cognitive performance is degraded when processing is slow because relevant operations cannot be successfully executed and because the products of early processing may no longer be available when later processing is complete." This is relevant in the case of the IWD group, where slower processing has been identified using the RT. This is in coherence with earlier findings in the literature that Dementia leads to slower cognitive processing for various tasks, especially that involve WM (Baddeley et al., 1986; Bragin et al., 2015; Stopford et al., 2012). This is also in support of the higher latencies/responses in evoked potential studies on MCI individuals (Fraga et al., 2017) which are identical to the findings of prolonged RT in the current study.

The familiarity of the stimulus should also be considered as one of the factors during WM assessment. The n-back task simultaneously taps both familiarity and recollection-based processes, and familiarity obscures the relation to recall-based complex items(Oberauer, 2005). This would lead to varied processing of different categories of stimuli along with the processing load. Findings of Park et al., (2002) reveal that that working memory is characterized by domain-specific subsystems and related but distinct visuospatial and verbal pools of working memory that mediate considerable variance in long-term memory. Findings of Carreiras et al., (2015), using fMRI suggest that processing may follow different brain pathways for different stimuli categories. They found that some brain areas responded more to letters than to numbers and other stimuli and vice versa for NTI. The above findings are also supported by Ngiam et al., (2019), where the visual working memory varied with the familiarity of letters. The familiarity of the participants with the basic alphabets of the Kannada language has led to a better threshold for the stimuli category of alphabets than other categories within the IWD group. These findings are in support of the varied processing of different semantic categories of stimuli. Thus, the present study is an evident contribution to the cognitive-linguistic processing ability being affected in individuals with Dementia.

Conclusions

The results of the present study revealed that NTI had better working memory capacity than IWD as measured using distinct linguistic processing of the n-back tasks. Category-specific differences (n-back threshold) were also found across both the groups, which suggest that the processing involved is different for different semantic categories. An objective testing procedure like an n-back task can aid in faster recognition of MCI and Dementia following the routine subjective assessment of Dementia.

Future implications:

The present study was carried out on a small population and examined the working memory of the participants up to the 4-back level. Future studies can be taken up involving more number of participants and can investigate the effect of increased levels of n-back in different clinical populations.

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Figure 1. An example of 2-back using lexical item fruits

Figure 2. Mean reaction time for various semantic categories with respect to specific threshold obtained by Individual with Dementia and Neurotypical individuals

Table 1: Results of descriptive statistics for Sem-back task of individuals with Dementia and neuro-typical individuals

Working memory tasks Sem- Back tasks for	**Groups**			
	Individuals with Dementia		**Neuro-typical Adults**	
	Mean	**SD**	**Mean**	**SD**
1. Lexical category 'Fruits'				
Sem1- Back	4132	87	1742	137
Sem2- Back	4555	310	1980	343
Sem3- Back	4379	305	2073	353
Sem4- Back	NR*	NR	2709	316
2. Lexical category 'Vehicles'				
Sem1- Back	3537	410	1546	149
Sem2- Back	3529	474	2129	367
Sem3- Back	3627	557	2302	308
Sem4- Back	NR	NR	2949	469
3. Lexical category 'Common Objects'				
Sem1- Back	4423	500	1527	163
Sem2- Back	4170	527	1833	268
Sem3- Back	NR	NR	2140	298
Sem4- Back	NR	NR	2859	433
4. 'Alphabets'				
Sem1- Back	3395	628	1463	187
Sem2- Back	3796	129	1782	143
Sem3- Back	4210	616	2361	423
Sem4- Back	4368	537	2790	393
5. 'Numbers'				
Sem1- Back	2723	225	1486	154
Sem2- Back	4274	437	2074	343
Sem3- Back	4182	510	2475	412
Sem4- Back	NR	NR	3009	539

*NR- No Response; Individuals with Dementia, n=7; Neuro-typical Adults, n=10.

Table 2. Results of Mann Whitney U-test at lexical category and the respective threshold level for Neurotypical Individuals and Individuals with Dementia

Lexical Category	Threshold for NTI	Threshold for IWD	/Z/ value	*P*-Value*
Common Objects	Sem4- Back	Sem2- Back	3.254	0.000
Fruits	Sem4- Back	Sem3- Back	3.416	0.000
Vehicles	Sem4- Back	Sem3- Back	2.278	0.022
Numbers	Sem4- Back	Sem3- Back	3.062	0.001
Alphabets	Sem4- Back	Sem4- Back	3.254	0.000

*Significant difference across both the groups ($P<0.05$) for all the categories

Table 3. Results of Friedman's test for Neurotypical Individuals and Individuals with Dementia

Group	Neurotypical Individuals		Individuals with Dementia	
	Chi-square value	*P*-Value	Chi-square value	*P*-Value
Sem1- Back	12.40	0.015*	19.09	0.001$
Sem2- Back	9.36	0.053	8.80	0.066
Sem3- Back	11.04	0.026*	5.70	0.127
Sem4- Back	3.44	0.487	CNT^	CNT^

*Significant ($P<0.05$) for Sem1-back and Sem3-back; $Significant ($P<0.05$) for Sem1-back; ^Could not test due to lack of groups

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