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The Hopkins Verbal Learning Test: An In-depth Analysis of Recall Patterns

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Running header: The Hopkins Verbal Learning Test Recall Analysis

1 **Abstract**

2

3 One of the earliest signs of dementia is memory issues and verbal word lists, such as the  
4 Hopkins Verbal Learning Test (HVLT), are successfully used for screening. To gain insight  
5 in how memory is affected in dementia, and to further improve the efficacy of the HVLT, in-  
6 depth analysis of the recall patterns of dementia cases and controls was conducted. Dementia  
7 cases and controls were matched for factors that can affect performance, such as age, gender  
8 and education level. Word frequency, syllable length, and orthographic neighbourhood size  
9 did not differ in the Indonesian version of the HVLT, nor did these characteristics affect  
10 recall. However dementia cases showed consistent and poor recall across the three trials; with  
11 the worst recall for the 'human shelter' category and best recall for the 'animals' category.  
12 Dementia cases also showed impaired accessibility of all categories with reduced subsequent  
13 recall from accessed categories and reduced primacy and recency levels. Finally, dementia  
14 cases exhibited lower levels of re-remembering and recalling new words, and higher levels of  
15 immediate forgetting and never recalling words. It was concluded that utilising the extra  
16 information provided by the in-depth analyses of the recall patterns could be beneficial to  
17 improve dementia screening.

18

19 198 words (max allowed is 200 words)

20

21

22

23 **Keywords:** Dementia; Hopkins Verbal Learning Test; HVLT; memory; recall patterns

24

25

1           The majority of dementia cases are expected to reside in developing countries  
2 (Hogervorst et al., 2011; Prince et al., 2015). Therefore, it is crucial that effective but easily  
3 administered, low technology screening tests for dementia are available which ideally could  
4 be administered without the need for specialist training or equipment. . The Hopkins Verbal  
5 Learning Test (HVLТ; Brandt, 1991) is one such screening test that we believe holds promise  
6 for use in developing countries (Hogervorst et al., 2011; Xu, Rahardjo, Xiao & Hogervorst,  
7 2014)..

Commented [SS1]: This information is quite important,I would not remove it

8           The HVLТ is a short test of verbal memory taking around ten minutes to administer  
9 (Brandt, 1991).

10           The HVLТ has been favourably compared to other dementia tests, such as: the Mini-  
11 Mental Status Examination (MMSE) (e.g., de Jager, Schrijnemaekers, Honey & Budge, 2009;  
12 Frank & Byrne, 2000; Kuslansky et al., 2004), the California Verbal Learning Test (CVLT)  
13 (Lacritz & Cullum, 1998; Lacritz, Cullum, Weiner & Rosenberg, 2001), CogState (de Jager,  
14 et al., 2009), subtests of the Wechsler Memory Scale-Revised (Shapiro, Benedict, Schretlen  
15 & Brandt, 1999), and the Brief Visuospatial Memory Test–Revised (Shapiro et al., 1999).  
16 The HVLТ has also been compared to less commonly used tests and has been shown to be  
17 more effective in screening for dementia (see Benedict, Schretlen, Groninger, Dobraski &  
18 Shpritz, 1996; Shapiro et al., 1999). The HVLТ has been adapted and/or translated for use in  
19 multiple countries (e.g., French: Rieu, Bachoud-Lévi, Laurent, Jurion, & Dallabarba, 2006;  
20 Spanish: Cherner et al., 2007; Chinese: Shi, Tian, Wei, Miao & Wang, 2012; Indonesian:  
21 Hogervorst et al., 2011). It is well tolerated by participants and is suitable for repeated testing  
22 due to its six different forms with minimal learning effects and no ceiling effects (Benedict et  
23 al., 1998; Krebs, 1994; Rasmusson, Bylisma & Brandt, 1995; Woods et al., 2005). An optimal  
24 cut-off score for the HVLТ for dementia cases is 16 to 17 words (total of 3 trials)  
25 immediately recalled, but this may vary depending on the country (and translation use) where

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1 it is used and/or the age of participants (see Xu, Rahardjo, Xiao & Hogervorst, 2014 for a  
2 review). The HVLТ displays good sensitivity and specificity for dementia in both Western  
3 (Friedman, Schinka, Mortimer & Graves, 2002; Hester, Kinsella, Ong & Turner, 2004;  
4 Hogervorst et al., 2002) and non-Western countries (Hogervorst et al., 2011; Shi et al., 2012;  
5 Xu et al., 2014).

6         Given the extent of previous research studying the HVLТ it is perhaps surprising that  
7 research exploring in-depth performance of dementia patients is very limited. A highly  
8 similar test, the CVLT (Delis, Kramer, Kaplan, & Ober, 1987), had explored performance  
9 over a wide range of in-depth analyses, such as semantic clustering (the degree to which  
10 items from the same category are recalled together), primacy and recency levels, learning  
11 rates, intrusion errors, etc. However, within the HVLТ, the total recall score is the main  
12 measure used for assessment. It is useful for quick identification of probable dementia  
13 patients (those who fall below the cut-off score), but the total recall score fails to investigate  
14 whether there are any subtler differences within the recall of probable dementia patients and  
15 controls.

16         Only a few papers have explored HVLТ recall in more depth. The most relevant of  
17 these is Schrijnemaekers, de Jager, Hogervorst and Budge (2006) who provided a brief  
18 examination of category recall and serial position effects in an Oxfordshire based cohort of  
19 cases and controls. Serial position effects refer to the finding that the location of an item  
20 within the list affects its likelihood of being remembered. Primacy effects refer to the recall  
21 advantage for words at the start of the list, and recency effects refers to the recall advantage  
22 for words at the end of the list (e.g., Jahnke, 1965; Murdock, 1962; Roberts, 1972).  
23 Schrijnemaekers et al. (2006) explored whether there were differences in the recall of the  
24 three HVLТ categories for trials 1 and 3 only. They did not find a significant difference for  
25 dementia cases, however, the trend in both trials 1 and 3 was for better recall of the category

1 'animals' compared to the categories 'semi-precious stones' and 'human shelter'. Dementia  
2 cases recall of all three categories was significantly poorer than controls. They also assessed  
3 primacy and recency effects via a grouped serial position analysis for trial 3 only. Recall was  
4 significantly lower for dementia cases. Controls showed no primacy and recency effects, but  
5 dementia cases showed both. This paper provides an interesting, albeit limited, assessment of  
6 recall patterns within the HVLТ.

7 Primacy and recency effects on other word lists have been investigated within  
8 dementia research. Typically dementia cases show an impaired primacy effect in word list  
9 recall, but a relatively preserved recency effect and so this may be diagnostically useful (e.g.,  
10 Bayley et al., 2000; Carlesimo, Fadda, Sabbadini, & Caltagirone, 1996; Foldi, Brickman,  
11 Schaefer, & Knutelska, 2003; Gainotti & Marra, 1994; Howieson et al., 2011; Massman,  
12 Delis, & Butters, 1993; Tierney et al., 1994).

13 Other papers have focused on semantic clustering within the HVLТ. This can be  
14 assessed if the order in which the words are recalled is recorded (output order). Gaines,  
15 Shapiro, Alt and Benedict (2006) compared semantic clustering indexes in healthy US based  
16 adults, patients with probable dementia of Alzheimer's type and patients with vascular  
17 dementia. Both types of dementia patients showed lower levels of semantic clustering than  
18 controls. Lower levels of semantic clustering within the HVLТ have also been found with  
19 amnesic mild cognitive impairment (aMCI) patients compared to controls (Malek-Ahmadi,  
20 Raj & Small, 2011). This tendency for impaired semantic clustering is well-known within  
21 dementia patients (e.g., Carlesimo et al., 1998; Delis et al., 1991; Glosser, Gallo, Clark &  
22 Grossman, 2002; Hodges et al., 1999; Perri, Carlesimo, Serra, & Caltagirone, 2005;  
23 Weingartner et al., 1981).

24 As well as the aspects discussed above, there are several general characteristics that  
25 can affect the ability to remember a word, such as word frequency, word length (number of

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1 syllables), age-of-acquisition, and orthographic neighbourhood size. Surprisingly, although  
2 the HVLТ allows for analysis of each word, no previous papers have investigated the effect  
3 of these characteristics on recall of the individual words. Therefore it is currently unknown  
4 how these characteristics vary within the HVLТ and what effect dementia might have on  
5 recall. There is also a lack of research investigating these characteristics within dementia  
6 patients' performance in *free* recall tasks.

7 Word frequency is perhaps the most important characteristic. However, most research  
8 conducted on dementia patients has focused on recognition tasks where the low frequency  
9 advantage observed in recall tasks dramatically decreases or disappears (Balota, Burgess,  
10 Cortese & Adams, 2002; Wilson, Bacon, Fox, Kramer & Kaszniak, 1983). Preserved word  
11 (syllable) length effects in memory span (serial recall) have been shown within dementia  
12 patients (Belleville, Peretz & Malenfant, 1996; Morris, 1984).

13 The expected effect of age-of-acquisition is more complex. Within healthy individuals  
14 some papers have found better recall for late acquired words in dementia (Dewhurst, Hitch &  
15 Barry, 1998; Morris, 1981) whilst others have found no effect (Christian, Bickley, Tarka, &  
16 Clayton, 1978; Coltheart & Winograd, 1986; Gilhooly & Gilhooly, 1979; Rubin, 1980).

17 Studies investigating age-of-acquisition in dementia patients have focused on word naming,  
18 picture naming and lexical decision tasks. They consistently find an advantage for early  
19 acquired words on these tasks (e.g., Cuertos, Herrera & Ellis, 2010; Forbes-McKay, Ellie,  
20 Shanks & Vennen, 2005; Kremin, Hamerel, Dordain, De Wilde & Perrier, 2000; Ralph,  
21 Graham, Ellis & Hodges, 1998; Silveri, Cappa, Mariotti & Puopolo, 2002) which is in line  
22 with healthy individuals (e.g., Barry, Morrison, & Ellis, 1997; Carroll & White, 1973;  
23 Gerhand & Barry, 1998; Morrison & Ellis, 1995).

24 Dementia patients have shown improved performance for words with larger numbers  
25 of orthographic neighbours within a recognition task using Spanish speakers (Dunabeitia,

Commented [SS2]: Bit of a shame to take that all out

1 Marín & Carreiras, 2009). This pattern has been mirrored within the normal population in  
2 serial recall tasks (memory span and immediate serial recall) (Allen & Hulme, 2006; Glanc &  
3 Greene, 2012; Jalbert, Neath, Bireta & Surprenant, 2011; Jalbert, Neath & Surprenant, 2011;  
4 Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002).

5 In the current paper we sought to investigate whether these four characteristics varied  
6 at the category and individual word level in Form 1 of the HVLТ in both English and  
7 Indonesian languages<sup>1</sup>. We are the first to explore the effects of word frequency, word length,  
8 age-of-acquisition and orthographic neighbourhood size on performance of dementia cases  
9 within the HVLТ in either English or Indonesian and the first to compare the two languages<sup>2</sup>.  
10 Whilst finalising the current paper, a highly relevant paper was published that looked at  
11 effects of word frequency, word length, and orthographic neighbourhood size within controls  
12 and dementia cases utilising the German version of the CVLT (Hessler, Fischer & Jahn,  
13 2016). They found that word length had no effect on recall for either controls or dementia  
14 cases, that word frequency showed an overall advantage for high frequency words for both  
15 controls and dementia cases, and that controls displayed better recall with high orthographic  
16 neighbourhood size, whereas dementia cases showed better recall with low orthographic  
17 neighbourhood size.

18 In-depth analysis of the HVLТ may allow for greater understanding of the nature of  
19 the memory impairment that causes reduced recall within dementia cases. As discussed  
20 earlier, dementia cases consistently show a reduced ability to utilise semantic information  
21 indicating an encoding issue. Furthermore, dementia cases show a large range of issues:  
22 impaired performance in both recollection (e.g., free recall) and familiarity (e.g., old/new and  
23 forced-choice recognition) tasks, a lack of learning over repeated exposure, impaired recall

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<sup>1</sup> The data were collected from Indonesian speaking participants

<sup>2</sup> Indonesian uses the Latin alphabet making direct comparison easier



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1 consistency, reduced subjective organisation, increased sensitivity to proactive interference,  
2 higher rates of forgetting, greater susceptibility to intrusions, higher rates of false alarms,  
3 greater number of perseverative errors, and impaired retention over time (e.g., Algarabel et  
4 al., 2009, 2012; Ally, Gold & Budson, 2009; Butters et al., 1983; Butters, Granholm,  
5 Salmon, Grant, & Wolfe, 1987; Dallabarba & Wong, 1995; Dannenbaum, Parkinson &  
6 Inman, 1988; Delis et al., 1991; Granholm & Butters, 1988; Grober & Buschke, 1987; Koen  
7 & Yonelinas, 2014; Kopelman, 1991; Martin, Brouwers, Cox, & Fedio, 1985; Ober, Koss,  
8 Friedland, & Delis, 1985; Perri et al. 2005; Weingartner et al., 1981; Weingartner, Grafman,  
9 Boutelle, Kaye & Martin, 1983; Wolk, Dunfee, Dickerson, Aizenstein & DeKosky, 2011).  
10 These findings indicate widespread issues with encoding, storage, and retrieval.

11         However, in most cases the issues researched above do not examine performance  
12 from trial to trial (except for recall consistency and subjective organisation). Repetition of the  
13 same words across three separate trials within the HVLTL allows examination of retrieval  
14 dynamics is possible via the tracking of each individual word from trial to trial. One can  
15 investigate which words are learnt, retained, and forgotten from trial to trial. Typically the  
16 *learning* research above uses a calculation of the difference between the number of words  
17 recalled in the last immediate trial compared to the first immediate trial and the *forgetting*  
18 rates are calculated as the difference between the number of words recalled in a delayed  
19 recall trial compared to the final immediate recall trial. Immediate forgetting from trial to trial  
20 is synonymous with failure to benefit from repeated exposure. However, these calculations  
21 are not sensitive as to specifically which words are being learnt or forgotten from trial to trial  
22 within immediate recall. The words recalled in the final immediate recall trial may be  
23 completely different words to the ones recalled in the first immediate recall trial, but if the  
24 number of words is the same, then no learning will be the reported outcome.

1           A few studies, however, have looked at intertrial performance to assess learning and  
2 forgetting with dementia cases. Woodard, Dunlosky and Salthouse (1999) examined intertrial  
3 acquisition and consolidation levels within six dementia cases. Utilising the Rey Auditory  
4 Verbal Learning test (Rey, 1964) they determined the levels of gained and lost items across  
5 adjacent trials. Gained items reflect acquisition (learning) and lost items reflect impaired  
6 consolidation (forgetting). Dementia cases had lower levels of learning and higher levels of  
7 forgetting suggesting impaired encoding and storage. These measures were also not  
8 correlated with each other, indicating that these assess independent processes.

9           Moulin, James, Freeman and Jones (2004) sought to replicate and extend Woodard et  
10 al.'s findings by utilising a larger sample, comparing controls with a MCI group and using a  
11 different test (CERAD word learning list; Welsh, Butters, Hughes, Mohs & Heyman, 1991).  
12 Like Woodard et al. they found significantly lower levels of gained items and higher levels of  
13 lost (forgotten) items for dementia cases, and no correlation between the two measures. In  
14 addition they also found that dementia cases were more impaired on both acquisition and  
15 consolidation measures compared to MCI cases, indicating that these both decline as  
16 dementia severity progresses. Additionally, Genon et al. (2013) utilised this gained and lost  
17 access criteria within another test (CVLT), and also confirmed deficient acquisition and  
18 consolidation levels with dementia cases whilst also providing the neural correlates.

19           We are the first to examine the levels of *re-remembered* (recalled in this trial and  
20 previously), *new* (recalled in this trial but not previously, akin to *gained access*), *forgotten*  
21 (not recalled in this trial but recalled previously, akin to *lost access*) and *never recalled* (not  
22 recalled in this trial or previously) words within the HVL. We also operationalise these  
23 calculations in a different way. Both Woodard et al. (1999) and Moulin et al. (2004) based  
24 their measures on consecutive trials. This means that a word recalled in trial 1 and 3 but not 2  
25 would be seen as a gained item (*new*) in trial 3 rather than a *re-remembered* item. Therefore

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1 we sought to eliminate this by amending our calculation to take into account recall of specific  
2 words from all previous trials.

3         The first author's previous work, looking at the recall patterns in two other immediate  
4 memory tasks (immediate free recall and immediate serial recall), has shown how important  
5 in-depth analysis can be to advance a field (Grenfell-Essam & Ward, 2012, 2015; Grenfell-  
6 Essam, Ward & Tan, 2013, 2017; Ward, Tan & Grenfell-Essam, 2010). We hope that a  
7 deeper exploration of the recall patterns of controls and dementia cases within the HVLТ may  
8 help improve its diagnostic efficacy. We are the first to investigate whether there are  
9 differences between word frequency, word length, age-of-acquisition and orthographic  
10 neighbourhood size within the 12 words of the HVLТ for both English and Indonesian  
11 languages<sup>3</sup> and the first to compare the two languages. We also investigated whether there  
12 were differences between controls and dementia cases on the total HVLТ score, the overall  
13 proportion of words recalled (allowing assessment of learning), category recall and  
14 accessibility, the effects of word frequency, word length, and orthographic neighbourhood  
15 size on recall<sup>4</sup>, the levels of primacy and recency (via serial position curves), and the retrieval  
16 dynamics across trials (via the levels of re-remembered, new, forgotten and never recalled  
17 words). The majority of these recall patterns have not been previously investigated within the  
18 HVLТ. We build upon a small number of studies that have investigated these areas by  
19 providing a more systematic exploration of recall within all trials and by utilising a larger  
20 sample.

21         The main aim of this paper is to improve the efficacy of the HVLТ by discovering  
22 whether, over a range of performance measures, there are differences between control and  
23 dementia cases. These more subtle differences between control and dementia cases, over and

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<sup>3</sup> Age-of-acquisition values were not available for the Indonesian version

<sup>4</sup> Using the Indonesian values

1 above the current overall recall measure currently used, may help screen for earlier signs of  
2 dementia.

3

#### 4 **Method**

5 **Sample.** Data were taken from Hogervorst et al. (2011), which was interested in  
6 investigating the validation of the HVLТ and MMSE dementia screening tests in Indonesia.  
7 The data was from a cross-sectional study involving 719 elderly Indonesian participants from  
8 West Java, Central Java and Jakarta (see Hogervorst et al., 2011 and Yesufu, Bandelow,  
9 Rahardjo & Hogervorst, 2009 for specific details of the study design). Informed consent had  
10 been obtained before study onset and ethical approval had been obtained from a local  
11 Indonesian ethical committee, as well as from Loughborough University in the United  
12 Kingdom.

13 **Cognitive measures.** Three cognitive measures taken from Hogervorst et al. (2011)  
14 were used in this study: HVLТ (Brandt 1991), MMSE (Folstein, Folstein & McHugh, 1975),  
15 and Instrumental Activities of Daily Living (IADL, Lawton & Brody, 1969). The latter two  
16 measures were used to classify control and dementia cases.

17 *HVLТ:* This test consists of three trials; each trial contains the same 12 words taken  
18 from three semantic categories (four words from each category). There are six forms to the  
19 test; form 1 was used containing four-legged animals (referred hereafter as *animals*), precious  
20 stones (referred hereafter as *stones*), and human dwellings (referred hereafter as *shelter*). The  
21 words are read out loud by the experimenter at a rate of around one word every two seconds.  
22 At the end of each trial participants' immediate free recall of the words is recorded. A total  
23 immediate recall measure is obtained by summing the total number of words correctly  
24 recalled from each trial. The maximum total immediate recall score possible is 36. An  
25 Indonesian version of the HVLТ was used (Hogervorst et al., 2011) and as such all analyses

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1 unless otherwise stated are based on this Indonesian version. Back-translation and focus  
2 groups were used to further validate the test items for local use. Note that Hogervorst et al.  
3 (2011) modified some of the words from the '*precious stones*' category to suit local  
4 knowledge following a pilot study<sup>5</sup>.

5 *MMSE*: This test consists of 11 questions that can be used to assess mental status  
6 across a range of five aspects of cognitive ability (orientation, registration, attention and  
7 calculation, recall, and language). Note that Hogervorst et al. (2011) adapted the questions for  
8 local circumstances similar to Ganguli et al.'s (1995) Hindi version. The maximum score  
9 possible is 30 and a cut-off score of 24 or less was adopted for dementia cases.

10 *IADL*: This test consists of eight activities, such as ability to use a telephone,  
11 housekeeping and responsibility for own medications, and scores their functional ability level  
12 for each activity. Note that Hogervorst et al. (2011) used a modified version that can be found  
13 within their article where the ability to perform each activity was scored from 0 (unable to  
14 do) to 2 (independent ability). The maximum score possible for this modified version is 16  
15 and a cut-off score of 9 or less was adopted for dementia cases.

16  
17 **Statistical Analyses.** We classified participants in the data set into control or  
18 dementia cases based on their scores on the MMSE and IADL. From the data set of 719  
19 participants, dementia cases were selected if they met all of the following three criteria: they  
20 had a MMSE score of 24 or less, an IADL score of 9 or less and had a recorded value for the  
21 Indonesian version of the HVLTL (i.e. no missing data). Control cases were selected if they  
22 met all the following three criteria: they had a MMSE score of 25 or more, an IADL score of  
23 10 or more and had a recorded value for the Indonesian version of the HVLTL. Using these  
24 criteria 216 participants were excluded because they did not match the cut-off criteria for

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<sup>5</sup> Please see Table 1 for details

1 either dementia or control based on their MMSE and/or IADL values and a further 31 were  
2 excluded because they had missing values for either HVLТ, MMSE or IADL. Differences in  
3 demographic characteristics (gender, age and education level) of the control and dementia  
4 cases were assessed via Chi-square and Mann-Whitney U tests. Due to significant differences  
5 between age and education level in the two groups a matched samples approach was adopted.  
6 Participants were matched by their gender, education level (exact match) and age (within 5  
7 years). A Mann-Whitney U test confirmed non-significant differences between the two  
8 groups in age.

9 A set of analyses were performed to examine the word frequency, word length, and  
10 orthographic neighbourhood size characteristics mentioned in the introduction and methods  
11 section for both English and Indonesian languages (see Table 1)<sup>6</sup>. This included a series of  
12 one-way analysis of variances (ANOVAs) with category (3 levels: animals, stones and  
13 shelter) as the independent variable and also a series of correlations to see whether any of the  
14 word characteristics were associated with each other. An independent sample t-test examined  
15 whether the HVLТ total recall score differed between dementia cases and controls. The  
16 overall proportion of words recalled across the three trials of the HVLТ was examined via a  
17 two-way mixed ANOVA. A set of analyses were performed to examine category recall and  
18 accessibility; this included a series of two-way mixed ANOVAs and also a series of chi-  
19 squares and independent samples t-tests. The relationship of word characteristics and recall  
20 was then assessed via a series of correlations. Serial positions curves, that allow assessment  
21 of primacy and recency within trials, were examined via a series of two-way mixed  
22 ANOVAs. Finally, the levels of learning and forgetting were investigated via a series of two-  
23 way mixed ANOVAs.

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<sup>6</sup> This is the only set of analyses which investigate the English version of the HVLТ.

1 For all two-way and three-way ANOVA analyses one of the independent variables  
2 was always group (dementia or control) and the results are reported within tables for clarity.  
3 Mauchly's Test of Sphericity was checked for all ANOVA analyses containing within-subject  
4 independent variables with more than two levels. Where Sphericity was violated the  
5 Greenhouse-Geisser correction was applied. Where significant main effects for within-subject  
6 variables occurred these were followed up via Bonferroni corrected pairwise comparisons.  
7 Where significant two-way interactions occurred these were followed up via simple effects  
8 using a Bonferroni correction. An alpha value of 0.05 was used for all statistical analyses  
9 unless otherwise stated and SPSS 23.0 was used.

10

## 11 **Results**

12 The data was considered in eight different analyses: participant demographics, word  
13 characteristics, HVLT total recall score, overall proportion of words recalled, category recall  
14 and accessibility, relationship of word characteristics and recall, serial position curves, and  
15 retrieval dynamics across trials.

16

17 **Participant demographics.** The first analysis investigated the demographic  
18 characteristics of the dementia and control groups. The criteria outlined in the method  
19 resulted in 76 dementia cases and 396 control cases. A Chi-square indicated that there was a  
20 non-significant difference for gender between the dementia group (Males = 32, Females =  
21 44) and control group (Males = 140, Females = 256),  $\chi^2(1) = 1.26, p = 0.263$ . However,  
22 Mann-Whitney U tests indicated that the dementia group (mean = 76.5, SD = 8.11) was  
23 significantly older than the control group (mean = 67.2, SD = 6.34),  $Z = -8.56, p < 0.001$ , and  
24 that the dementia group had a significantly lower education level than the control group,  $Z = -$   
25  $7.82, p < 0.001$ .

1           Due to the significant differences in age and education level between the control and  
2 dementia cases, a matched samples approach was adopted. Control and dementia participants  
3 were matched on gender (exact matches only), education level (exact matches only) and age  
4 (matches exact where possible but no further than 5 years apart). This resulted in 62 matched  
5 participants in each group (Males = 23, Females = 39). A Mann-Whitney U test indicated that  
6 there was no significant difference in age between the dementia group (mean = 74.6, SD =  
7 7.38) and the control group (mean = 73.5, SD = 6.47),  $Z = -.702$ ,  $p = 0.483$ . Full details of the  
8 demographic information of the participants can be found in Appendix 1.

9  
10           **Word characteristics.** This analysis explored whether the characteristics discussed in  
11 the introduction (word frequency, word length, age-of-acquisition, and orthographic  
12 neighbourhood size) vary within Form 1 of the HVLT in both English and Indonesian. Table  
13 1 shows the word frequency, word length (number of syllables), age-of-acquisition<sup>7</sup>, and  
14 orthographic neighbourhood size (based on Coltheart's N; Coltheart, Davelaar, Jonasson, &  
15 Besner, 1977) values for the words and categories in Form 1. For the English version: word  
16 frequency values represent number of occurrences per million words taken from Brysbaert  
17 and New (2009) which are based on the SUBTL database; age-of-acquisition values were  
18 taken from Kuperman, Stadthagen-Gonzalez and Brysbaert (2012); and orthographic  
19 neighbourhood size were based on Coltheart's N values from the CLEARPOND database  
20 (Marian, Bartolotti, Chabal & Shook, 2012). For the Indonesian version: word frequency  
21 values were taken from Hermit Dave (2016) and are based on the OpenSubtitles2016 data for  
22 Indonesian subtitles<sup>8</sup>. Orthographic neighbourhood size values were calculated by the first  
23 author by systematically substituting each letter individually with all possible letters of the

---

<sup>7</sup> No age-of-acquisition values within the Indonesian language were available

<sup>8</sup> These provide raw scores rather than values per million. This word frequency source was the only data set which provided values for all words within the Indonesian version of the HVLT



1 alphabet to make all possible combinations of orthographic neighbours. These words were  
2 then verified as real Indonesian words via at least three separate sources (a translation tool, an  
3 Indonesian dictionary and an Indonesian thesaurus).

4 -----  
5 --Table 1 about here--  
6 -----

7 Table 1 shows that the individual words display variation within the characteristics for  
8 both the English and Indonesian languages. In particular the word frequency values show a  
9 large range in both languages. These values cannot be directly numerically compared due to  
10 differences in measurement but they appear to follow similar trends. This was confirmed by a  
11 significant correlation,  $r(12) = 0.941$ ,  $p < 0.001$ . Word length shows much lower variability,  
12 but more similarity across the two languages (English 1-3 syllables; Indonesian 2-4 syllables)  
13 with only 1 word in both languages having the highest number of syllables. However, there  
14 was a non-significant correlation between the two languages for word length,  $r(12) < 0.001$ ,  
15  $p = 1.000$ . Age-of-acquisition values were only available for English but these displayed a  
16 wide range of 5.34 years. Orthographic neighbourhood size shows a wider range for English  
17 (English 0-24 neighbouring words; Indonesian 0-11 neighbouring words) but they appear to  
18 follow similar trends as confirmed by a significant correlation,  $r(12) = 0.796$ ,  $p = 0.002$ .

19 To investigate whether each characteristic varied at the category level, a series of one-  
20 way ANOVAs were conducted on each characteristic with category (3 levels: animals, stones  
21 and shelter) as the independent variable. For the English language these ANOVAs revealed  
22 non-significant differences between: frequency of occurrences per million,  $F(2, 9) = 1.25$ ,  
23  $MSE = 1119.0$ ,  $p = 0.331$ ; word length,  $F(2, 9) = 1.93$ ,  $MSE = 0.389$ ,  $p = 0.201$ ; and  
24 orthographic neighbourhood size values,  $F(2, 9) = 3.16$ ,  $MSE = 49.4$ ,  $p = 0.091$ . However,  
25 there was a significant difference between the age-of-acquisition,  $F(2, 9) = 14.6$ ,  $MSE =$

Running header: The Hopkins Verbal Learning Test Recall Analysis

1 1.18,  $p = 0.002$ . Bonferroni corrected pairwise comparisons showed that animals were  
2 acquired significantly earlier than both stones ( $p = 0.001$ ) and shelter ( $p = 0.038$ ), but that  
3 stones and shelter were not different ( $p = 0.147$ ). Additionally only two of the characteristics  
4 significantly correlated with each other: word length and orthographic neighbourhood size,  $r$   
5 (12) = -0.642,  $p = 0.024$ . All other correlations were not significant; word frequency and  
6 word length,  $r$  (12) = -0.123,  $p = 0.703$ , word frequency and age-of-acquisition,  $r$  (12) = -  
7 0.441,  $p = 0.151$ , word frequency and orthographic neighbourhood size,  $r$  (12) = -0.020,  $p =$   
8 0.950, word length and age-of-acquisition,  $r$  (12) = 0.484,  $p = 0.111$ , and age-of-acquisition  
9 and orthographic neighbourhood size,  $r$  (12) = -0.335,  $p = 0.287$ .

10 For the Indonesian language these ANOVAs exploring category differences also  
11 revealed non-significant differences between: word frequency,  $F$  (2, 9) = 2.18, MSE =  
12 1226176.1,  $p = 0.169$ ; word length,  $F$  (2, 9) = 1.50, MSE = 0.389,  $p = 0.274$ ; and  
13 orthographic neighbourhood size values,  $F$  (2, 9) = 0.525, MSE = 10.64,  $p = 0.609$ .  
14 Additionally none of the characteristics significantly correlated with each other: word  
15 frequency and word length,  $r$  (12) = -0.325,  $p = 0.302$ , word frequency and orthographic  
16 neighbourhood size,  $r$  (12) = 0.133,  $p = 0.680$ , and word length and orthographic  
17 neighbourhood size,  $r$  (12) = -0.552,  $p = 0.063$ .

18  
19 **HVLT total recall score.** The HVLT is usually scored using a total recall score. This  
20 is the sum of all words correctly recalled, including any re-remembered words, across the  
21 three immediate trials. The total recall score was 14.9 words ( $SD = 5.65$ ) for the control cases  
22 and 6.6 words ( $SD = 5.39$ ) for the dementia cases. This difference was statistically  
23 significant,  $t$  (122) = 8.36,  $p < 0.001$ , with a large effect size (Cohen's  $d = 1.5$ ).

24

1           **Overall proportion of words recalled.** Figure 1 shows the overall proportion of  
2 words recalled for the dementia and control groups for the three immediate trials of the  
3 HVL. It is evident that recall for all trials is substantially higher for the control group  
4 compared to dementia cases. There is a greater increase in recall occurring across trials for  
5 controls (14%) but a smaller increase in recall for dementia cases (3%).

6                                   -----  
7                                   --Figure 1 about here--  
8                                   -----

9  
10           Table 2 summarises a 2 (group: dementia or control) x 3 (trial: 1-3) mixed ANOVA  
11 performed to examine overall recall performance. There was a significant main effect of  
12 group; controls had significantly higher recall than dementia cases. There was a significant  
13 main effect of trial; pairwise comparisons using a Bonferroni correction indicated that recall  
14 significantly increased between each trial (trial 1 < trial 2 < trial 3). Finally, there was a  
15 significant interaction. Simple effects using a Bonferroni correction ( $p = 0.00556$ )  
16 comparing control and dementia cases within each trial were all significantly different (all  
17  $p$ 's < 0.001). Looking within the control cases only across trials, all comparisons were  
18 significantly different (all  $p$ 's < 0.001). However, looking within the dementia cases only  
19 across trials, there were no significant comparisons (all  $p$ 's > 0.100). Therefore the  
20 interaction was driven by the significantly increasing performance of controls across trials  
21 1-3, compared to the consistent and poor performance of dementia cases across trials 1-3.

22                                   -----  
23                                   --Table 2 about here--  
24                                   -----  
25

1           **Category recall and accessibility.** Figure 2 shows the proportion of words recalled  
2 for each category for the dementia and control groups for each of the three trials (Panel A –  
3 trial 1, Panel B – trial 2, and Panel C – trial 3). Panel D shows the overall proportion of words  
4 recalled from each category at any point during the three trials. In all four panels it is evident  
5 that recall for all categories is higher for the control group compared to dementia cases. Both  
6 control and dementia cases recalled the animal category the best, and the shelter category the  
7 worst.

8  
9                   -----  
10                   --Figure 2 about here--  
11                   -----

12           Table 2 summarises a series of four 2 (group: dementia or control) x 3 (category:  
13 animals, stones, and shelter) mixed ANOVAs performed to examine category recall  
14 performance in each of the four panels of Figure 2. For all ANOVAs the main effect of  
15 group was significant; controls had significantly higher recall of the categories than  
16 dementia cases. For all ANOVAs the main effect of category was significant. Bonferroni  
17 corrected pairwise comparisons indicated that for trial 2, trial 3 and overall trials 1-3  
18 analyses all categories were recalled significantly differently (all  $p$ 's < 0.001; shelter <  
19 stones < animals). However, for trial 1 animals were recalled significantly better than stones  
20 and shelter (both  $p$ 's < 0.001), but stones and shelter were not different ( $p = 0.100$ ). The  
21 interaction was not significant for trial 2, trial 3 and overall trials 1-3 analyses. However,  
22 the interaction was significant for trial 1. Simple effects using a Bonferroni correction ( $p =$   
23 0.00556) comparing control and dementia cases within each category were all significantly  
24 different (all  $p$ 's < 0.004). Looking across categories within the control cases only, animals  
25 were recalled significantly better than both stones and shelter (both  $p$ 's < 0.001) but there  
was a non-significant difference between stones and shelter ( $p = 0.036$ ). Looking across

1 categories within the dementia cases only, animals were recalled significantly better than  
2 both stones and shelter (both  $p$ 's  $< 0.002$ ) but there was a non-significant difference  
3 between stones and shelter ( $p = 0.397$ ). Therefore the interaction for trial 1 was driven by  
4 the difference in recall of stones compared to shelter between control and dementia cases –  
5 recall of these two categories was deemed non-significant for controls due to the Bonferroni  
6 correction but was highly non-significant for dementia cases.

7 The following analysis looks at category accessibility and subsequent number of  
8 words recalled to determine whether the overall category recall findings reflect different  
9 accessibility abilities for control and dementia cases. Figure 3 shows the percentage of  
10 participants who accessed each category within the three trials giving a measure of category  
11 accessibility (Panel A = trial 1, Panel B = trial 2, and Panel C = trial 3) and displays the  
12 average number of words recalled given that the category was accessed (Panel D = trial 1,  
13 Panel E = trial 2, and Panel F = trial 3). It appears that for all categories across all trials  
14 controls have a greater ability to access each category compared to controls. However, when  
15 looking at the subsequent number of words recalled there is a more consistent approximate  
16 0.5 word advantage for control over dementia cases. It also appears that in trial 1 there is a  
17 smaller difference between control and dementia cases in both the stones and shelter  
18 categories.

19 -----  
20 --Figure 3 about here--  
21 -----

22 Table 3 summarises a series of nine Chi-square analyses performed to examine  
23 category accessibility for control and dementia cases for each category within each trial  
24 (Figure 3, Panels A-C). All Chi-squares were significant indicating that for all categories  
25 across all trials the dementia cases had impaired accessibility compared to controls.

1            Table 3 also summarises a series of nine independent samples t-tests performed to  
2            compare the number of words recalled given the category was accessed for control and  
3            dementia cases for each category and each trial (Figure 3, Panels D-F). Note that mixed  
4            ANOVAs were not performed due to the low number of participants who accessed every  
5            category within a trial. Controls recalled significantly more words than dementia cases for  
6            the majority of categories and trials, apart from trial 1 stones and shelter.

7            -----

8            --Table 3 about here--

9            -----

10

11            **Relationship of word characteristics and recall.** A series of six correlations were  
12            performed to determine whether control and dementia cases recall performance (the average  
13            recall over trials 1-3 of the HVLТ) was related to the characteristics of word frequency, word  
14            length or orthographic neighbourhood size. None of the correlations were significant  
15            indicating that there is no relationship between these characteristics and recall performance.  
16            Control group: word frequency,  $r(12) 0.131$ ,  $p = 0.685$ , word length,  $r(12) 0.065$ ,  $p = 0.841$ ,  
17            and orthographic neighbourhood size,  $r(12) 0.028$ ,  $p = 0.932$ ; Dementia group: word  
18            frequency,  $r(12) 0.256$ ,  $p = 0.422$ , word length,  $r(12) -0.041$ ,  $p = 0.900$ , and orthographic  
19            neighbourhood size,  $r(12) 0.197$ ,  $p = 0.539$ .

20            For each characteristic within the Indonesian version the 12 words were median split  
21            into high and low frequency, short and long words, and small and large orthographic  
22            neighbourhood size<sup>9</sup>. Figure 4 shows the values for high and low word frequency (Panel A)  
23            and large and small orthographic neighbourhood size (Panel B) for both dementia and control  
24            groups.

---

<sup>9</sup> Word length was not analysed further due to the unequal median split (low = 9 words, high = 3 words)

1 -----  
2 --Figure 4 about here--  
3 -----

4 Table 4 summarises two 2 (group: dementia or control) x 2 (word characteristic: low  
5 or high) x 3 (trial: 1-3) mixed ANOVAs performed separately on the word frequency and  
6 orthographic neighbourhood size word characteristics to examine whether they have an effect  
7 on recall. The *overall proportion of words recalled* analysis reported earlier summarises the  
8 findings for the main effects of group and trial and the two-way interaction between them.  
9 Within the current analysis we are interested in the effects of word frequency and  
10 orthographic neighbourhood size. For word frequency the main effect and two-way  
11 interaction with trial were significant; high frequency words were recalled better than low  
12 frequency words. Simple effects using a Bonferroni correction ( $p = 0.00556$ ) comparing high  
13 and low frequency within each trial indicated that low frequency words were remembered  
14 significantly worse than high frequency words for trial 1 ( $p < 0.001$ ) but there were no  
15 significant differences for trials 2 and 3 (both  $p$ 's  $< 0.018$ ). Looking across trials within the  
16 high frequency words only, recall stayed the same across trials (trial 1 = trial 2 = trial 3).  
17 Looking across trials within the low frequency words only, recall significantly increased  
18 between each trial (trial 1 < trial 2 < trial 3). Therefore the interaction was driven by  
19 improvement in recall for the low frequency words as the test progressed. However, the two-  
20 way interaction between word frequency and group and the three way interaction between  
21 word frequency, group and trial were not significant. For orthographic neighbourhood size  
22 the main effect was significant; words with fewer orthographic neighbours were recalled  
23 better than words with more orthographic neighbours. However, all interactions were non-  
24 significant. Therefore both word frequency and orthographic neighbourhood size did not  
25 affect dementia cases and controls differently.

1 -----  
2 --Table 4 about here--  
3 -----

4  
5 **Serial position curves.** Figure 5 shows the serial position curves for the dementia and  
6 control groups for each of the three trials (Panel A – trial 1, Panel B – trial 2, and Panel C –  
7 trial 3). Panel D shows how likely each word was to be recalled across the three trials. Recall  
8 in all trials is higher for the control group compared to dementia cases. Both controls and  
9 dementia cases show increased recall for the start and end of the list, indicating primacy and  
10 recency respectively. However, for dementia cases in particular, this may well be a  
11 consequence of the placement of the words; serial positions 1, 3 and 11 are words from the  
12 highly recalled animal category.

13 -----  
14 --Figure 5 about here--  
15 -----

16 Table 5 summarises a series of four 2 (group: dementia or control) x 12 (serial  
17 position: 1-12) mixed ANOVAs performed to examine serial position performance in each of  
18 the four panels of Figure 5. For all ANOVAs the main effect of group was significant;  
19 controls had significantly higher recall than dementia cases. In addition, the main effect of  
20 serial position was significant; Bonferroni corrected pairwise comparisons indicated primacy  
21 and recency (the exact statistics can be found in Appendix 2 for trial 1, Appendix 3 for trial 2,  
22 Appendix 4 for trial 3, and Appendix 5 for trials 1-3). The interaction was not significant for  
23 trial 2, trial 3 and overall trials 1-3 analyses. However, the interaction was significant for trial  
24 1. Simple effects compared performance between the groups at each serial position only, as  
25 this was the main comparison of interest. Using a Bonferroni correction ( $p = 0.00417$ ), recall



1 for dementia cases was significantly lower than controls at serial positions 2, 3, and 9 (all  $p$ 's  
2 < 0.002). Therefore the interaction was driven by similar recall for dementia cases and  
3 controls except for serial positions 2, 3, and 9.

4 -----

5 --Table 5 about here--

6 -----

7  
8 **Retrieval dynamics across trials.** Figures 2 and 5 hint at the learning and forgetting  
9 that occurred across the trials. Within Figure 5 the dementia cases appeared to demonstrate  
10 low levels of learning across trials (i.e. adding new words), whereas the control group  
11 demonstrated higher levels particularly for the asymptote (middle) serial positions. However,  
12 Figure 5 only indicates overall increases or decreases in specific words over trials. It does not  
13 allow for a detailed understanding of the learning, retention and forgetting across trials for  
14 individual participants. Therefore for each participant, for each word, and across all trials, the  
15 number of times they retained, learnt or forgot a word was calculated in order to assess  
16 retrieval dynamics.

17 Table 6 shows the proportion of learning, retention and forgetting occurring across  
18 trials 2 and 3 for control and dementia cases. The data was divided into four categories: (1)  
19 *Re-remembered* means that a word was recalled on the current trial and had been recalled on  
20 previous trial(s) i.e., retention, (2) *New* means that it was recalled on the current trial but had  
21 not been recalled on any previous trial(s) i.e. learning, (3) *Forgotten* means that it was not  
22 recalled on the current trial but had been recalled on previous trial(s), (4) *Never recalled*  
23 means that it was not recalled on the current trial and had not been recalled on any previous  
24 trial(s). Control cases showed much greater levels of re-remembering and lower levels of  
25 words never recalled for trials 2 and 3 compared to dementia cases. However, the rates of

1 new words learnt and words forgotten for trials 2 and 3 appeared to be more similar for both  
2 control and dementia cases.

3 -----

4 --Table 6 about here--

5 -----

6 Table 7 summarises a series of four 2 (group: dementia or control) x 2 (trial: 2-3)  
7 mixed ANOVAs performed to examine the levels of re-remembered, new, forgotten, and  
8 never recalled words for controls and dementia cases shown in Table 7. For all ANOVAs the  
9 main effect of group was significant; compared to controls, dementia cases re-remembered,  
10 acquired, and forgot fewer words and never recalled more words. For all ANOVAs the main  
11 effect of trial was significant; fewer words were re-remembered and forgotten, and more  
12 words were acquired and never recalled in trial 2 compared to trial 3. The interaction was not  
13 significant for the new or forgotten words analyses. However, the interactions were  
14 significant for the re-remembered and never recalled words analyses. Looking first at the re-  
15 remembered interaction simple effects, using a Bonferroni correction ( $p = 0.0125$ ), indicated  
16 that controls re-remembered significantly more than dementia cases for both trial 2 and 3  
17 (both  $p$ 's  $< 0.001$ ) and the amount of re-remembered words significantly increased between  
18 trial 2 and 3 for both control and dementia cases (both  $p$ 's  $< 0.002$ ). Therefore, this  
19 interaction was driven by dementia cases showing significantly lower levels of re-  
20 remembering than controls for both trials 2 and 3. Looking now at the never recalled  
21 interaction simple effects, using a Bonferroni correction ( $p = 0.0125$ ), indicated that the  
22 amount of words never recalled was significantly higher for dementia cases compared to  
23 controls for both trial 2 and 3 (both  $p$ 's  $< 0.001$ ) and the amount of words never recalled  
24 significantly decreased between trial 2 and 3 for both control and dementia cases (both  $p$ 's  $<$

1 0.001). Therefore, the interaction was driven by dementia cases showing significantly higher  
2 levels of words never recalled than controls for both trials 2 and 3.

3 -----  
4 --Table 7 about here--  
5 -----

6 Due to the difference between the number of words of the HVLTL list remembered by  
7 controls and dementia cases, perhaps a more accurate comparison to assess retrieval  
8 dynamics would be to calculate the proportion of words acquired and forgotten *relative* to the  
9 proportion of the list previously recalled. For example, dementia cases appear to have  
10 forgotten more words than controls in the above analysis but this is because they remember  
11 less than controls to start with. Looking at the words forgotten relative to the proportion of  
12 the list previously recalled, controls show the same proportion of words that they forgot  
13 across the two trials (trial 2 = 29% of the list previously remembered, trial 3 = 29% of the list  
14 previously remembered). Dementia cases also show a very similar, albeit higher than  
15 controls, proportion of words that they forgot across the two trials (trial 2 = 41% of the list  
16 previously remembered, trial 3 = 42% of the list previously remembered). Looking at the  
17 words newly acquired relative to the proportion of the list previously recalled, controls show  
18 a very similar proportion of newly acquired words across the two trials (trial 2 = 26% of the  
19 list yet to be recalled, trial 3 = 27% of the list yet to be recalled). However, dementia cases  
20 show a lower- but greater- difference in the proportion of the remaining list that they acquire  
21 across the two trials (trial 2 = 11% of the list yet to be recalled, trial 3 = 7% of the list yet to  
22 be recalled).

23  
24 **Discussion**

25 The aim of this paper was to investigate in-depth recall patterns within the HVLTL to  
26 determine whether there are important subtle differences between control and dementia cases

1 recall that are not currently being captured using the total immediate recall score. We hoped  
2 that any novel findings might lead to improvement in the efficacy of the HVLТ.

3         As expected the dementia cases had a much lower total immediate recall score on the  
4 HVLТ compared to controls. However, we found dementia cases exhibited widespread  
5 impairments across all analyses. The dementia cases showed no improvement in recall across  
6 the three trials in agreement with previous research of diminished learning rates (Delis et al.,  
7 1991; Ober et al., 1985; Perri et al., 2005; Weingartner et al., 1981, 1983). Focusing on recall  
8 within the three categories of the HVLТ, dementia cases showed poorest recall of the human  
9 shelter category and best recall for the animals category; although for trial 1 stones and  
10 human shelter recall were not different. These trends were mirrored in the control cases,  
11 albeit at higher recall values. This is in contrast to Schrijnemaekers et al. (2006) who found  
12 no significant difference between recall of the three categories. Although their trends  
13 revealed animals were recalled best, stones and shelter were equally poorly recalled.  
14 However, it is important to note that Schrijnemaekers et al. study utilised an English sample  
15 and the English version of the HVLТ whereas we utilised an Indonesian sample and an  
16 Indonesian version of the HVLТ. Cultural differences can impact on category recall, possibly  
17 related to the following linguistic aspects.

18         The linguistic characteristics we were able to analyse did not reveal significant  
19 differences on any of our measures between the categories. Therefore another linguistic  
20 feature that we could not measure may be driving these differences. Age-of-acquisition is a  
21 potential characteristic that could be causing these differences. The English age-of-  
22 acquisition values showed that animals were acquired significantly earlier than both stones  
23 and shelter with Schrijnemaekers et al. (2006) non-significant findings exactly mirroring  
24 these trends. Dementia cases show a robust advantage for early acquired words over a range  
25 of tasks (Cuetos et al., 2010; Forbes-McKay et al., 2005; Kremin et al., 2000; Ralph et al.,

Grenfell-Essam, R., Hogervorst, E. & Rahardjo, T. B. W. (in prep)

1 1998; Silveri et al., 2002). We also found dementia cases had reduced accessibility to all  
2 categories within all trials compared to controls. Given (that?) the category accessed,  
3 dementia cases subsequent recall was also impaired relative to controls in accord with  
4 previous research (Martin & Fedio, 1983; Ober, Dronkers, Koss, Delis & Friedland, 1986).

Commented [SS3]: This sentence reads odd

5 Dementia cases often display a reduced primacy effect, but a relatively preserved  
6 recency effect relative to controls (e.g., Bayley et al., 2000; Carlesimo et al., 1996; Foldi et  
7 al., 2003; Gainotti & Marra, 1994; Howieson et al., 2011; Massman et al., 1993; Tierney et  
8 al., 1994). However, we found reduced levels of both primacy and recency for dementia cases  
9 compared to controls. This discrepant finding may be due to the recency effect declining with  
10 the severity of dementia (Pepin & Eslinger, 1989). Whilst recency levels were reduced,

Commented [SS4]: Not sure what you are trying to say

11 dementia cases did show significant levels of primacy and recency within their recall.  
12 However, we are concerned that the higher proportion of the well-remembered animals  
13 category at the start and end of the list (serial positions 1, 3 and 11) may be inflating primacy  
14 and recency levels. Due to this confound, it is unclear whether the improved performance is  
15 due to one or both of these factors. In addition three of the words from the shelter category  
16 are in the middle serial positions (4, 6 and 7) which may contribute to their poorer recall.

Commented [SS5]: Good point

17 Other memory tests used to screen for dementia present the words in a random order each  
18 time (e.g., CVLT, Delis et al., 1987; CERAD word learning list, Welsh et al., 1991) which  
19 eliminates these confounds. However, this may be one of the reasons why floor effects are  
20 not usually reported on the HVL. To help disentangle these issues future work could  
21 manipulate the presentation order of the words by either presenting the words in a random  
22 order for each trial or, perhaps more interestingly, by systematically varying the location of  
23 the categories within the list such that that one word of each category occurs in all four  
24 sections of the list.

1            Looking in detail at the intertrial retrieval dynamics revealed that dementia cases did  
2 recall new words in trials 2 and 3 despite not showing a significant increase in learning from  
3 trial 1 to 3 overall. However, dementia cases did learn significantly less than controls.  
4 Dementia cases also recall significantly less of the list and, relative to the proportion of the  
5 list already recalled, also forgot more words, mirroring the findings for gained and lost access  
6 (Genon et al., 2013; Moulin et al., 2004; Woodward et al., 1999). Dementia cases appear to  
7 have deficits in both learning and consolidation indicating issues with encoding and storage,  
8 respectively. It would appear from these results and previous findings (Algarabel et al., 2009,  
9 2012; Ally et al., 2009; Butters et al., 1983, 1987; Carlesimo et al., 1998; Dallabarba &  
10 Wong, 1995; Dannenbaum et al., 1988; Delis et al., 1991; Gaines et al., 2006; Genon et al.,  
11 2013; Glosser et al., 2002; Granholm & Butters, 1988; Grober & Buschke, 1987; Hodges et  
12 al., 1999; Koen & Yonelinas, 2014; Kopelman, 1991; Martin et al., 1985; Moulin et al., 2004;  
13 Ober et al., 1985; Perri et al. 2005; Weingartner et al., 1981, 1983; Wolk et al., 2011;  
14 Woodward et al., 1999) that dementia cases have impairment at all stages of memory  
15 (encoding, storage, and retrieval).

16            What was interesting were the relative rates across trials 2 and 3 of the proportion of  
17 newly acquired words and the loss of previously recalled words. With regards to immediate  
18 forgetting rates, the proportion of forgotten words changed by less than 1% across trials 2 and  
19 3 for both control and dementia cases, showing that whilst immediate forgetting rates are  
20 higher in dementia cases, they follow a similar trend. Acquisition rates are slightly more  
21 divergent between dementia cases and controls. Controls show a stable rate of acquisition  
22 across trials 2 and 3, however, dementia cases show a decrease in acquisition rates, even  
23 though in absolute terms they have a much larger number of never recalled words to draw  
24 from. These rates of immediate forgetting and, in particular, acquisition might be a useful  
25 diagnostic tool alongside the total recall score to be able to differentiate between dementia

1 and other memory disorders, such as aMCI, which often displays results in-between dementia  
2 cases and controls.

3         Additionally we also looked at several linguistic characteristics of the words within  
4 the HVLТ. This data set was collected with Indonesian speaking participants but we analysed  
5 the linguistic features of the 12 words of Form 1 of the HVLТ for both English and  
6 Indonesian languages as these characteristics have never been researched before, in either  
7 language or within the HVLТ. We found that the two languages provided broadly similar  
8 findings. The English and Indonesian languages were strongly correlated for both word  
9 frequency and orthographic neighbourhood size characteristics. Within each language, all but  
10 one characteristic did not correlate with each other, indicating that these linguistic measures  
11 are relatively independent. For both languages word frequency, word length, and  
12 orthographic neighbourhood size did not vary across the three categories of Form 1 of the  
13 HVLТ. However, there were two differences between the two languages. Firstly, there was  
14 no correlation between the English and Indonesian languages for word length, although this is  
15 most likely due to the lack of variation within the data. Secondly, within the English language  
16 there was a relationship between word length and orthographic neighbourhood size which  
17 was non-significant within the Indonesian language. Therefore the use of Indonesian  
18 language may have partially affected the results we may have expected with an English  
19 speaking sample. We also found age-of-acquisition did vary across the categories within the  
20 English version, but no comparison with Indonesian was possible due to the lack of values for  
21 age-of-acquisition. Therefore, we were also unable to determine the possible effect of age-of-  
22 acquisition on recall within the current data. Previous research has not looked at recall  
23 (Cuetos et al., 2010; Forbes-McKay et al., 2005; Kremin et al., 2000; Ralph et al., 1998;  
24 Silveri et al., 2002). We would be keen to address this within future research.

1 We also investigated the effect of these characteristics on recall. We found that  
2 neither word frequency nor orthographic neighbourhood size had a differential effect on  
3 recall in control and dementia cases. However, we did find an overall word frequency effect;  
4 high frequency words were recalled better than low frequency words, for both control and  
5 dementia cases. This is in line with previous findings from recall tasks for controls (Deese,  
6 1960; Postman, 1970; Sumbly, 1963) and the only study to investigate dementia cases with  
7 free recall (Hessler et al., 2016). We also found an overall effect of orthographic  
8 neighbourhood size; where words with fewer orthographic neighbours produced better recall  
9 for both control and dementia cases. Hessler et al. (2016) also found better recall with fewer  
10 orthographic neighbours for dementia cases. However, they found the opposite pattern in  
11 control cases. Previous research using serial recall also supports Hessler et al.'s finding for  
12 controls (Allen & Hulme, 2006; Glanc & Greene, 2012; Jalbert, Neath, Bireta & Surprenant,  
13 2011; Jalbert, Neath & Surprenant, 2011; Roodenrys et al., 2002). We are not certain why our  
14 results differ, but one possibility may be due to the much smaller vocabulary of Indonesian  
15 compared to German and English affording the possibility of fewer orthographic neighbours.  
16 Further research investigating the effect of orthographic neighbourhood size within free recall  
17 would address this current discrepancy.

18 These linguistic findings reveal the importance of the appropriate and careful  
19 selection of words for verbal recall tests and have an impact on the construction of future  
20 word based dementia screening tests and the potential updating of current tests. Much  
21 research in dementia uses the levels of primacy and recency as a marker for diagnosis.  
22 However, the tests that they utilise do not look at the linguistic characteristics of each  
23 individual word. The effects of these four characteristics may not be uniform across the list  
24 and therefore be producing a confound between serial position and these characteristics. For  
25 example, word frequency appears to affect pre-recency locations (Raymond, 1969; Sumbly,

Commented [SS6]: interesting



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1 1963). However, more recently word frequency has been found to affect recency positions  
2 (Van Overschelde, 2002) but these discordant findings may be due to the use of pure and  
3 mixed frequency lists. Word frequency may also affect where recall is initiated within the list  
4 which then has a knock-on effect in recall. Recall is more likely to be initiated with the first  
5 word in the list for high frequency words, but towards the end of the list for low frequency  
6 words (Sumbly, 1963). Grenfell-Essam and colleagues have shown that where recall is  
7 initiated has a large effect on primacy and recency (Grenfell-Essam & Ward, 2012, 2015;  
8 Grenfell-Essam et al., 2013, in press; Ward et al., 2010).

9 We have shown that both word frequency and orthographic neighbourhood size affect  
10 recall, with the effect of age-of-acquisition unknown. As the HVLTL repeats the words in the  
11 same order in each list this makes an in-depth analyses of the linguistic characteristics of the  
12 five other forms of the HVLTL all the more important. In the future to avoid either floor or  
13 ceiling effects, the difficulty of tests can be altered by adjusting the word frequency, word  
14 length, age-of-acquisition and/or orthographic neighbourhood size. Indeed the CVLT-II  
15 utilises higher frequency words specifically to avoid floor effects (Delis, Kramer, Kaplan &  
16 Ober, 2000). Researchers need to also carefully consider the location of these items within  
17 the list and whether the words are presented in the same, or random, order.

18 This study does have some limitations. Our algorithm for dementia was validated in  
19 several studies in Indonesia (see Hogervorst et al., 2011), However, future work needs to  
20 further validate this work in clinically established dementia cases and controls. Another  
21 limitation is the translation of the test which does not allow transference of results to other  
22 cultures. Future work should look at a range of cultures to investigate the generalisability of  
23 our results. The translation of this test into Indonesian also did not allow for the characteristic  
24 of age-of-acquisition to be assessed or use of established word frequency and orthographic  
25 neighbourhood size corpora.

Commented [SS7]: I do not agree, see letter

1           There are several ways in which this research can be pursued in the future. Firstly, the  
2 fact that the HVLТ has six different forms is a strength of the test, as it allows for repeated  
3 testing (Benedict et al., 1998; Krebs, 1994; Rasmusson et al., 1995; Woods et al., 2005). We  
4 wish to collect data that would allow us to extend our novel set of analyses to determine  
5 whether the six forms are actually equivalent based on the findings from Form 1 in this paper.  
6 Secondly, it was unknown at the time of data collection that the data would be used for in-  
7 depth analysis and therefore output order was not recorded. Output order data would have  
8 enabled recall consistency and semantic clustering analyses to be performed that are known  
9 to be reduced in dementia recall (e.g., Carlesimo et al., 1998; Delis et al., 1991; Gaines et al.,  
10 2006; Glosser et al., 2002; Hodges et al., 1999; Perri et al., 2005; Weingartner et al., 1981).  
11 Recording output order would also have allowed for analysis of where in the list participants  
12 initiate their recall. There may be differences in the starting point of recall between controls  
13 and dementia patients, and also differences in whether the same word is chosen as the first  
14 word in trials 1, 2 and 3. Output order also allows the full sequence to be investigated  
15 allowing for assessment, for each participant, of how similar recall is from trial to trial.  
16 Thirdly, we would also like to reproduce this work, along with the added output order  
17 analyses, in an English sample as changes to some of the stones were necessary to  
18 accommodate local knowledge and we were also unable to examine the possible effect of  
19 age-of-acquisition. The linguistic characteristics may have a large effect on primacy and  
20 recency. Finally, we would also be keen to extend this in-depth analysis of HVLТ with other  
21 populations, such as vascular dementia and very early dementia cases (e.g. possible  
22 Alzheimer’s disease or aMCI), to see whether there are distinct patterns of deficits that can be  
23 identified to once again help improve the efficacy of this test. Indeed, due to the widespread  
24 impairments of dementia cases across all performance measures in this study, it might be  
25 more useful to profile earlier deficits in patients with aMCI. aMCI patients may show less

1 widespread patterns of impairment that when tracked over time might be shown to be more  
2 likely to lead to dementia.

3 In conclusion, this paper has demonstrated that there are important differences  
4 between control and dementia case recall that are not captured in the total recall score. We  
5 have demonstrated that, within the HVLT, dementia cases exhibit: consistent and poor recall  
6 across the three trials, poorest recall for shelter, but best for animals, impaired accessibility of  
7 all categories and reduced subsequent recall from accessed categories, reduced recall at the  
8 start and end of the list, lower levels of re-remembering and recalling new words; and higher  
9 levels of forgetting and never recalling words. These differences help characterise in more  
10 detail the exact nature of the reduced recall performance of dementia cases compared to  
11 controls, and when used alongside the total recall score, may help improve the efficacy of the  
12 HVLT. This research may help improve the diagnostic ability and accuracy of the HVLT to  
13 detect earlier stages of dementia than currently possible. It could also be valuable when  
14 monitoring individuals over time to identify subtle changes in HVLT performance not  
15 captured with the total recall score. Finally, it might prove beneficial in assessment of  
16 treatment efficacy. Therefore, going forward this research may have wide reaching  
17 implications.

18

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25



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11

12

1 **Appendix Captions**

2 Appendix 1: Full demographic information for the age, gender and educational level matched  
3 participants in the Dementia and Control groups. Note: participants on the same row were  
4 matched.

5  
6 Appendix 2: Pairwise comparisons, with a Bonferroni correction, to follow up the significant  
7 main effect of serial position for trial 1 (Figure 5, Panel A). The values show the significance  
8 level; significant values are indicated in bold.

9  
10 Appendix 3: Pairwise comparisons, with a Bonferroni correction, to follow up the significant  
11 main effect of serial position for trial 2 (Figure 5, Panel B). The values show the significance  
12 level; significant values are indicated in bold.

13  
14 Appendix 4: Pairwise comparisons, with a Bonferroni correction, to follow up the significant  
15 main effect of serial position for trial 3 (Figure 5, Panel C). The values show the significance  
16 level; significant values are indicated in bold.

17  
18 Appendix 5: Pairwise comparisons, with a Bonferroni correction, to follow up the significant  
19 main effect of serial position for trials 1-3 (Figure 5, Panel D). The values show the  
20 significance level; significant values are indicated in bold.

21

## 1 Appendix 1.

2

Gender	Education level	Age (in years)	
		Control cases	Dementia cases
Female	Primary school	81	85
Female	Primary school	83	88
Female	Elementary school (unfinished)	60	60
Female	Elementary school (unfinished)	70	70
Female	Elementary school (unfinished)	77	77
Female	Elementary school (unfinished)	78	83
Female	Elementary school (unfinished)	66	66
Female	Elementary school (unfinished)	68	68
Female	Elementary school (unfinished)	81	85
Female	Elementary school	62	62
Female	Elementary school	74	74
Female	Elementary school	75	75
Female	Elementary school	75	76
Female	Elementary school	75	75
Female	Elementary school	85	85
Female	Elementary school	86	86
Female	High school	74	75
Female	No formal education	60	60
Female	No formal education	67	67
Female	No formal education	68	68
Female	No formal education	70	70
Female	No formal education	70	70
Female	No formal education	85	85
Female	No formal education	65	66
Female	No formal education	80	80
Female	No formal education	65	65
Female	No formal education	70	70
Female	No formal education	70	70
Female	No formal education	70	70
Female	No formal education	71	73
Female	No formal education	70	70
Female	No formal education	70	70
Female	No formal education	76	76
Female	No formal education	75	75
Female	No formal education	75	75
Female	No formal education	77	77
Female	No formal education	78	78
Female	No formal education	80	80
Female	No formal education	82	83
Male	Elementary school (unfinished)	60	60
Male	Elementary school (unfinished)	65	66
Male	Elementary school (unfinished)	68	69
Male	Elementary school (unfinished)	71	71
Male	Elementary school (unfinished)	76	79

Running header: The Hopkins Verbal Learning Test Recall Analysis

Male	Elementary school (unfinished)	76	80
Male	Elementary school (unfinished)	77	80
Male	Elementary school (unfinished)	80	83
Male	Elementary school (unfinished)	82	87
Male	Elementary school	70	70
Male	Elementary school	72	72
Male	Elementary school	76	76
Male	Elementary school	76	78
Male	Elementary school	76	80
Male	Elementary school	80	85
Male	Elementary school	81	86
Male	No formal education	75	75
Male	No formal education	76	80
Male	No formal education	60	61
Male	No formal education	70	70
Male	No formal education	76	74
Male	No formal education	73	73
Male	No formal education	76	80

- 1
- 2
- 3
- 4

Appendix 2.

SP	2	3	4	5	6	7	8	9	10	11	12
1	<b>0.004</b>	1.000	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	<b>0.015</b>	1.000	<b>0.006</b>	1.000	0.241
2		0.133	1.000	1.000	1.000	0.065	1.000	1.000	1.000	<b>0.021</b>	1.000
3			< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	0.459	1.000	0.099	1.000	1.000
4				1.000	1.000	1.000	1.000	<b>0.004</b>	1.000	< <b>0.001</b>	0.215
5					1.000	1.000	0.573	<b>0.003</b>	1.000	< <b>0.001</b>	0.163
6						1.000	0.671	<b>0.014</b>	1.000	< <b>0.001</b>	0.322
7							<b>0.007</b>	< <b>0.001</b>	<b>0.036</b>	< <b>0.001</b>	<b>0.002</b>
8								1.000	1.000	0.091	1.000
9									1.000	1.000	1.000
10										<b>0.010</b>	1.000
11											0.189

Running header: The Hopkins Verbal Learning Test Recall Analysis

Appendix 3.

SP	2	3	4	5	6	7	8	9	10	11	12
1	0.338	1.000	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	0.238	0.747	1.000	1.000	1.000
2		0.164	0.153	0.227	1.000	< <b>0.001</b>	1.000	1.000	1.000	1.000	1.000
3			< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	0.074	0.103	1.000	1.000	1.000
4				1.000	1.000	1.000	0.072	0.054	<b>0.009</b>	<b>0.001</b>	<b>0.002</b>
5					1.000	1.000	0.796	0.360	0.082	<b>0.012</b>	<b>0.019</b>
6						1.000	1.000	1.000	0.259	0.109	0.325
7							<b>0.006</b>	<b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>
8								1.000	1.000	1.000	1.000
9									1.000	1.000	1.000
10										1.000	1.000
11											1.000

Appendix 4.

SP	2	3	4	5	6	7	8	9	10	11	12
1	1.000	1.000	< <b>0.001</b>	<b>0.015</b>	0.702	< <b>0.001</b>	0.723	1.000	1.000	1.000	1.000
2		1.000	<b>0.001</b>	0.086	0.245	< <b>0.001</b>	0.859	0.881	1.000	1.000	1.000
3			< <b>0.001</b>	<b>0.001</b>	<b>0.032</b>	< <b>0.001</b>	0.078	<b>0.043</b>	1.000	1.000	1.000
4				1.000	1.000	1.000	1.000	1.000	0.146	<b>0.007</b>	<b>0.005</b>
5					1.000	1.000	1.000	1.000	1.000	0.241	0.117
6						0.059	1.000	1.000	1.000	1.000	1.000
7							0.054	<b>0.022</b>	<b>0.002</b>	< <b>0.001</b>	< <b>0.001</b>
8								1.000	1.000	1.000	1.000
9									1.000	1.000	1.000
10										1.000	1.000
11											1.000

Running header: The Hopkins Verbal Learning Test Recall Analysis

Appendix 5.

SP	2	3	4	5	6	7	8	9	10	11	12
1	<b>0.007</b>	1.000	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	<b>0.001</b>	<b>0.005</b>	<b>0.044</b>	1.000	0.103
2		<b>0.030</b>	<b>0.010</b>	0.082	0.407	< <b>0.001</b>	1.000	1.000	1.000	1.000	1.000
3			< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	<b>0.003</b>	< <b>0.001</b>	0.125	1.000	0.286
4				1.000	1.000	1.000	0.069	0.121	0.012	< <b>0.001</b>	<b>0.005</b>
5					1.000	1.000	0.230	0.389	0.239	< <b>0.001</b>	<b>0.048</b>
6						0.146	1.000	1.000	0.715	<b>0.006</b>	0.106
7							< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>
8								1.000	1.000	0.842	1.000
9									1.000	1.000	1.000
10										1.000	1.000
11											1.000



### **Table Captions**

Table 1. Characteristics of Form 1 of the Hopkins Verbal Learning Test: word frequency, word length (number of syllables), age-of-acquisition, and orthographic neighbourhood size for both English and Indonesian languages.

Table 2. Summary of the ANOVA analyses conducted on the overall proportion of words recalled and the proportion of words recalled by category for trial 1, trial 2, trial 3 and overall for trials 1-3.

Table 3. The likelihood of accessing each category across trials 1-3 for the Control and Dementia cases.

Table 4. Summary of the ANOVA analyses conducted on the proportion of words recalled as a function of word frequency and orthographic neighbourhood size for trials 1-3.

Table 5. Summary of the ANOVA analyses conducted on the serial position curves for trial 1, trial 2, trial 3, and overall for trials 1-3.

Table 6. The learning and retention percentages across trials 2 and 3 for the Control and Dementia cases.

Table 7. Summary of the ANOVA analyses conducted on the proportion of re-remembered, new, forgotten, and never recalled words.

Table 1.

	English version					Indonesian version			
	Words	Word frequency (per million)	Word length (syllables)	Age of acquisition (years)	Orthographic neighbourhood size	Words	Word frequency	Word length (syllables)	Orthographic neighbourhood size
1	lion	15.35	1	4.42	4	singa	923	2	1
2	emerald	2.57	3	8.26	0	intan	21	2	3
3	horse	92.88	1	4.15	8	kuda	3584	2	4
4	tent	17.49	1	5.16	15	tenda	485	2	5
5	sapphire	1.20	2	9.22	0	akik*	1	2	4
6	hotel	103.22	2	6.05	2	hotel	3160	2	1
7	cave	13.98	1	6.74	17	gua	1513	2	4
8	opal	1.02	2	9.28	2	kecubung*	3	3	0
9	tiger	18.53	2	4.00	3	harimau	583	3	0
10	pearl	15.67	1	6.28	1	mutiara	305	4	0
11	cow	25.51	1	3.94	24	sapi	1401	2	11
12	hut	13.22	1	8.10	17	gubuk	144	2	4
Average (SD)	Overall	26.72 (32.75)	1.50 (0.65)	6.30 (1.94)	7.75 (7.94)		1010.25 (1168.21)	2.33 (0.62)	3.08 (2.98)
	Animals	38.07 (31.86)	1.25 (0.43)	4.13 (0.19)	9.75 (8.44)		1622.75 (1169.02)	2.25 (0.84)	3.20 (4.30)
	Stones	5.12 (6.12)	2.00 (0.71)	8.26 (1.21)	0.75 (0.83)		82.50 (128.70)	2.75 (0.83)	1.40 (1.74)
	Shelter	36.98 (38.28)	1.25 (0.43)	6.51 (1.07)	12.75 (6.26)		1325.50 (1172.92)	2.00 (0.00)	2.80 (1.50)

Note: \*denotes non-direct translations: akik = agate, kecubung = amethyst.

Table 2.

	<i>df</i>	<i>MSE</i>	<i>F</i>	<i>p</i>
<i>Overall proportion of words recalled*</i>				
Group	1, 122	10.2	69.9	<.001
Trial	1.785, 217.7	1.46	25.8	<.001
Group x trial	1.785, 217.7	1.46	11.2	<.001
<i>Proportion of words recalled by category for trial 1*</i>				
Group	1, 122	0.073	37.5	<.001
Category	1.904, 232.3	0.046	49.7	<.001
Group x category	1.904, 232.3	0.046	6.01	0.003
<i>Proportion of words recalled by category for trial 2</i>				
Group	1, 122	0.082	61.0	<.001
Category	2, 244	0.044	31.0	<.001
Group x category	2, 244	0.044	1.43	0.243
<i>Proportion of words recalled by category for trial 3*</i>				
Group	1, 122	0.110	69.3	<.001
Category	1.897, 231.4	0.044	17.9	<.001
Group x category	1.897, 231.4	0.044	0.593	0.554
<i>Proportion of words recalled by category for trials 1-3</i>				
Group	1, 122	0.154	66.0	<.001
Category	2, 244	0.049	43.1	<.001
Group x category	2, 244	0.049	0.807	0.447

Note: \* indicates the initial assumption checks indicated that Mauchly's Test of Sphericity was violated therefore degrees of freedom were corrected using the Greenhouse-Geisser correction.

Table 3.

	Chi-square			t-test	
	$\chi^2$	<i>p</i>	<i>df</i>	<i>t</i>	<i>p</i>
<i>Trial 1</i>					
Animal	7.49	0.006	93	2.96	0.004
Stones	7.64	0.006	59	1.32	0.191
Shelter	8.18	0.004	55	0.34	0.739
<i>Trial 2</i>					
Animal	6.86	0.009	92	2.78	0.007
Stones	9.76	0.002	76.7	4.02*	< 0.001
Shelter	11.48	<0.001	54.7	2.79*	0.007
<i>Trial 3</i>					
Animal	8.49	0.004	90	3.30	0.001
Stones	12.68	<0.001	84	3.37	0.001
Shelter	11.69	<0.001	71	3.45	0.001

Note: \* indicates the initial assumption checks indicated that Levene's Test for Equality of Variances was violated therefore the equal variance not assumed values were reported.

Table 4.

	<i>df</i>	<i>MSE</i>	<i>F</i>	<i>p</i>
<i>Word frequency</i>				
Group	1, 122	0.141	69.91	<.001
Word frequency	1, 122	0.054	11.77	.001
Trial*	1.785, 217.7	0.018	25.84	<.001
Group x word frequency	1, 122	0.054	0.07	.792
Group x trial	2, 244	0.018	11.22	<.001
Word frequency x trial	2, 244	0.017	5.59	.004
Group x word frequency x trial	2, 244	0.017	2.20	.114
<i>Orthographic neighbourhood size</i>				
Group	1, 122	0.141	69.91	<.001
Orthographic N	1, 122	0.046	5.97	.016
Trial*	1.785, 217.7	0.018	25.84	<.001
Group x orthographic N	1, 122	0.046	2.72	.102
Group x trial	2, 244	0.018	11.22	<.001
Orthographic N x trial	2, 244	0.023	0.36	.701
Group x orthographic N x trial	2, 244	0.023	0.37	.694

Note: \* indicates the initial assumption checks indicated that Mauchly's Test of Sphericity was violated therefore degrees of freedom were corrected using the Greenhouse-Geisser correction.

Table 5.

	<i>df</i>	<i>MSE</i>	<i>F</i>	<i>p</i>
<i>Serial position curve for trial 1*</i>				
Group	1, 122	0.293	37.5	<.001
Serial position	9.214, 1124.2	0.187	12.8	<.001
Group x serial position	9.214, 1124.2	0.187	1.90	0.036
<i>Serial position curve for trial 2*</i>				
Group	1, 122	0.330	61.0	<.001
Serial position	9.694, 1182.7	0.194	10.8	<.001
Group x serial position	9.694, 1182.7	0.194	1.30	0.217
<i>Serial position curve for trial 3*</i>				
Group	1, 122	0.440	69.3	<.001
Serial position	9.493, 1158.2	0.200	8.53	<.001
Group x serial position	9.493, 1158.2	0.200	1.25	0.248
<i>Serial position curve for trials 1-3*</i>				
Group	1, 122	0.616	66.0	<.001
Serial position	9.581, 1168.9	0.191	16.3	<.001
Group x serial position	9.581, 1168.9	0.191	0.929	0.511

Note: \* indicates the initial assumption checks indicated that Mauchly's Test of Sphericity was violated therefore degrees of freedom were corrected using the Greenhouse-Geisser correction.

Table 6.

SP	1	2	3	4	5	6	7	8	9	10	11	12	Total	
Word	<i>Lion</i>	<i>Emerald</i>	<i>Horse</i>	<i>Tent</i>	<i>Sapphire</i>	<i>Hotel</i>	<i>Cave</i>	<i>Opal</i>	<i>Tiger</i>	<i>Pearl</i>	<i>Cow</i>	<i>Hut</i>		
CONTROL GROUP														
<b>Trial 2</b>	Re-remembered	0.37	0.26	0.44	0.11	0.13	0.13	0.06	0.19	0.39	0.24	0.35	0.24	0.24
	New	0.21	0.23	0.21	0.13	0.10	0.13	0.11	0.26	0.10	0.23	0.11	0.26	0.17
	Forgotten	0.16	0.08	0.13	0.08	0.05	0.05	0.03	0.13	0.13	0.03	0.19	0.10	0.10
	Never recalled	0.26	0.44	0.23	0.68	0.73	0.69	0.79	0.42	0.39	0.50	0.34	0.40	0.49
<b>Trial 3</b>	Re-remembered	0.50	0.48	0.53	0.18	0.18	0.21	0.10	0.35	0.40	0.35	0.48	0.53	0.36
	New	0.11	0.15	0.10	0.10	0.19	0.24	0.11	0.10	0.08	0.15	0.08	0.10	0.13
	Forgotten	0.24	0.08	0.24	0.15	0.10	0.10	0.11	0.23	0.21	0.15	0.18	0.06	0.15
	Never recalled	0.15	0.29	0.13	0.58	0.53	0.45	0.68	0.32	0.31	0.35	0.26	0.31	0.36
DEMENTIA GROUP														
<b>Trial 2</b>	Re-remembered	0.23	0.06	0.13	0.02	0.06	0.08	0.02	0.06	0.10	0.06	0.19	0.15	0.10
	New	0.13	0.08	0.19	0.03	0.05	0.06	0.02	0.08	0.05	0.16	0.10	0.08	0.09
	Forgotten	0.13	0.05	0.11	0.05	0.02	0.02	0.03	0.11	0.05	0.10	0.13	0.06	0.07
	Never recalled	0.52	0.81	0.56	0.90	0.87	0.84	0.94	0.74	0.81	0.68	0.58	0.71	0.75
<b>Trial 3</b>	Re-remembered	0.23	0.13	0.32	0.05	0.06	0.11	0.03	0.16	0.08	0.18	0.24	0.15	0.15
	New	0.05	0.11	0.05	0.08	0.06	0.03	0.03	0.00	0.06	0.05	0.03	0.06	0.05
	Forgotten	0.26	0.06	0.11	0.05	0.06	0.05	0.03	0.10	0.11	0.15	0.18	0.15	0.11
	Never recalled	0.47	0.69	0.52	0.82	0.81	0.81	0.90	0.74	0.74	0.63	0.55	0.65	0.69

Guide to categories: *Re-remembered* means that it was recalled on the current trial and had been recalled on previous trial(s), *New* means that it was recalled on the current trial but had not been recalled on any previous trial(s), *Forgotten* means that it was not recalled on the current trial but it had been recalled on previous trial(s), *Never recalled* means that it was not recalled on the current trial and had not been recalled on any previous trial(s).

Table 7.

	<i>df</i>	<i>MSE</i>	<i>F</i>	<i>p</i>
<i>Proportion of re-remembered words</i>				
Group	1, 122	0.421	57.3	<.001
Trial	1, 122	0.101	49.5	<.001
Group x trial	1, 122	0.101	8.32	0.005
<i>Proportion of new words</i>				
Group	1, 122	1.51	37.3	<.001
Trial	1, 122	1.20	12.1	0.001
Group x trial	1, 122	1.20	0.337	0.563
<i>Proportion of forgotten words</i>				
Group	1, 122	2.49	4.39	0.038
Trial	1, 122	0.709	27.9	<.001
Group x trial	1, 122	0.709	1.12	0.293
<i>Proportion of never recalled words</i>				
Group	1, 122	12.7	60.7	<.001
Trial	1, 122	0.500	14.1	<.001
Group x trial	1, 122	0.500	23.5	<.001



### Figure Captions

Figure 1. Mean proportion of words recalled overall for trials 1-3 in the HVLТ for control and dementia cases.

Figure 2. Mean proportion of words recalled within each category of the HVLТ for control and dementia cases for trial 1 (A), trial 2 (B), and trial 3 (C). Panel D shows the overall likelihood of recalling the words within the category across the three trials.

Figure 3. Percentage of participants accessing each category for trial 1 (A) trial 2 (B), and trial 3 (C) and average number of words recalled given the category was accessed for trial 1 (D), trial 2 (E), and trial 3 (F) for control and dementia cases.

Figure 4. Mean proportion of words recalled for trials 1-3 in the HVLТ for control and dementia cases for high and low frequency words (A) and large and small orthographic neighbourhood size words (B).

Figure 5. Overall serial position curves for control and dementia cases for trial 1 (A), trial 2 (B), and trial 3 (C). Panel D shows the overall likelihood of recalling each word across the three trials.

Figure 1.

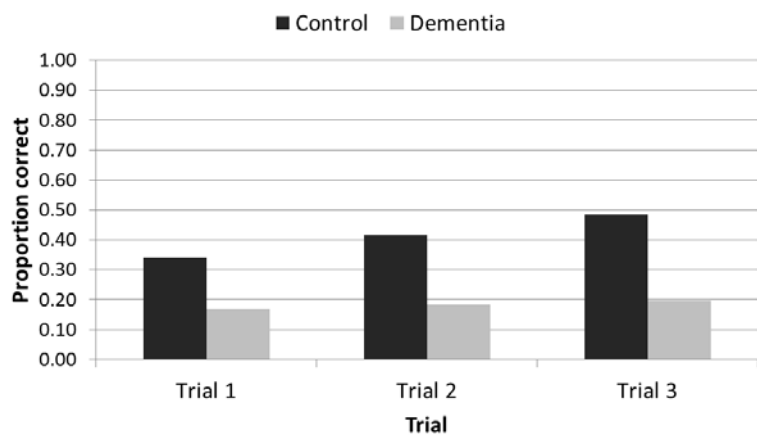


Figure 2.

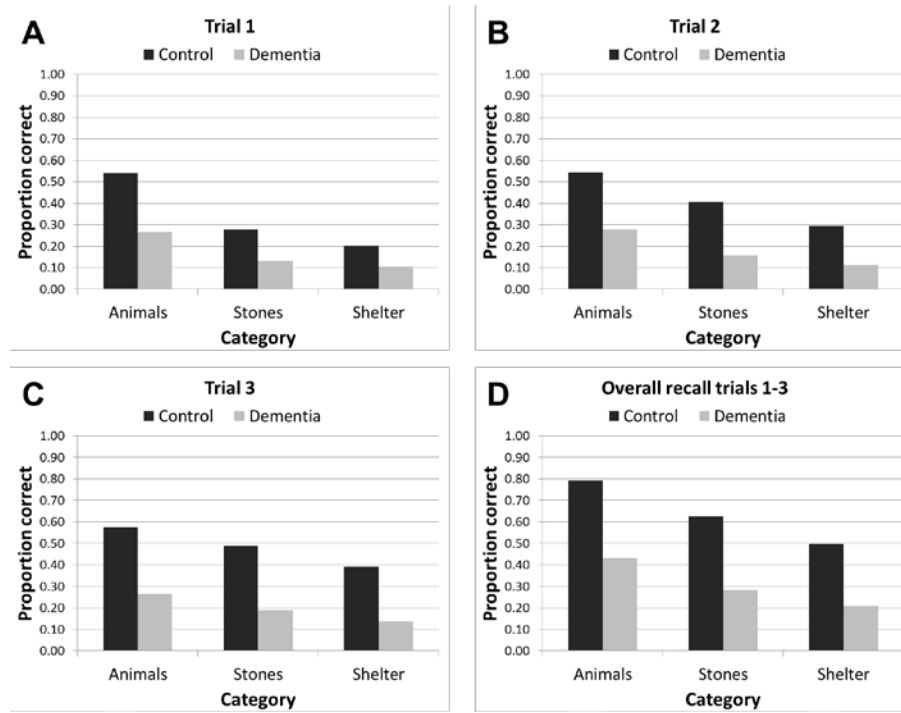


Figure 3.

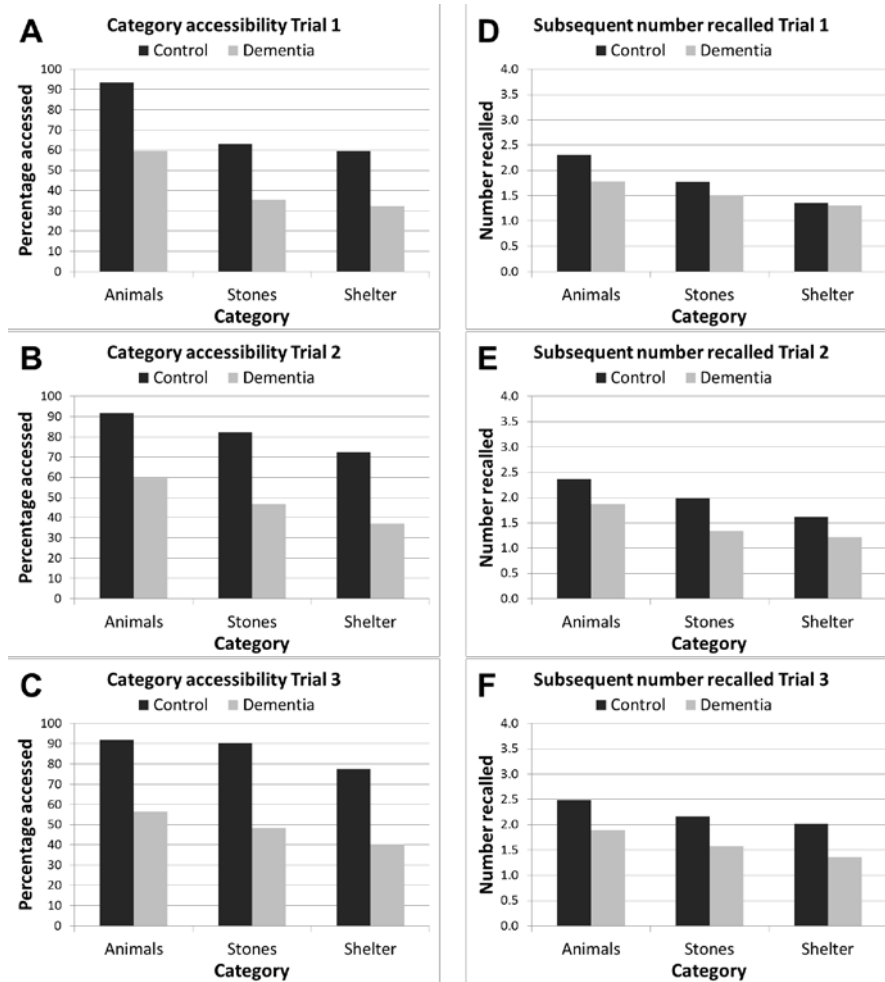


Figure 4.

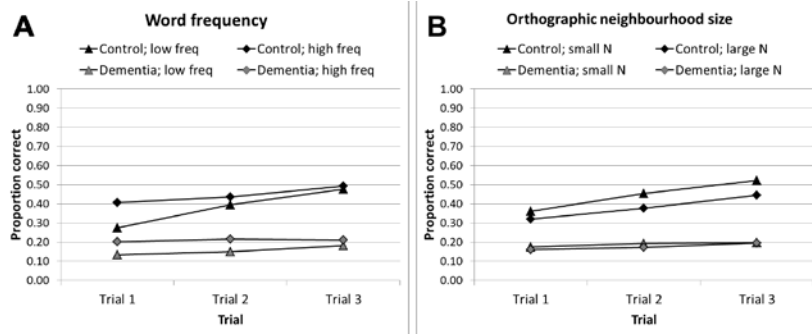


Figure 5.

