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Remembering ‘zeal’ but not ‘thing’: Reverse frequency effects as a consequence of deregulated semantic processing

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Abstract

More efficient processing of high frequency (HF) words is a ubiquitous finding in healthy individuals, yet frequency effects are often small or absent in stroke aphasia. We propose that some patients fail to show the expected frequency effect because processing of HF words places strong demands on semantic control and regulation processes, counteracting the usual effect. This may occur because HF words appear in a wide range of linguistic contexts, each associated with distinct semantic information. This theory predicts that in extreme circumstances, patients with impaired semantic control should show an outright reversal of the normal frequency effect. To test this prediction, we tested two patients with impaired semantic control with a delayed repetition task that emphasised activation of semantic representations. By alternating HF and low frequency (LF) trials, we demonstrated a significant repetition advantage for LF words, principally because of perseverative errors in which patients produced the previous LF response in place of the HF target. These errors indicated that HF words were more weakly activated than LF words. We suggest that when presented with no contextual information, patients generate a weak and unstable pattern of semantic activation for HF words because information relating to many possible contexts and interpretations is activated. In contrast, LF words tend are associated with more stable patterns of activation because similar semantic information is activated whenever they are encountered.

Keywords: word frequency, repetition, perseveration, semantic aphasia, semantic diversity

Introduction

It is an almost ubiquitous finding in studies of language processing that high frequency (HF) words are processed more efficiently than low frequency (LF) words. This is true, for example, in picture naming (Oldfield, 1966), reading aloud (Forster & Chambers, 1973) and lexical decision (Balota & Chumbley, 1984). As a consequence, computational models of language typically incorporate a HF word advantage. In connectionist models that learn representations through training, HF words have stronger connection weights as a consequence of being presented more often as the model is trained (Plaut, McClelland, Seidenberg, & Patterson, 1996; Rogers & McClelland, 2004). In other lexical access models, HF words are assumed to have higher resting of levels of activation that allow them to overcome lexical competition more quickly (Dell, 1989; Stemberger, 1985). In all these models, it is a general principle that HF words are processed more efficiently and this tendency should if anything be exaggerated under brain damage. It is surprising, then, that frequency effects are often small or absent in stroke aphasia (e.g., Hoffman, Rogers, & Lambon Ralph, in press; Jefferies & Lambon Ralph, 2006; Nickels & Howard, 1995). Moreover, aphasic patients can occasionally show an outright *reversal* of the frequency effect, such that LF words are processed more successfully than HF words. Such cases are very rare; we are only aware of two reports in the literature (Crutch & Warrington, 2005; Marshall, Pring, Chiat, & Robson, 2001). In this study, we present data from two patients who show this unusual effect in a delayed repetition task that requires maintenance of semantic knowledge. We link the reverse frequency pattern to their established deficits in regulating semantic knowledge, proposing that the meanings of HF words have higher intrinsic cognitive control demands.

Our experimental hypotheses are derived from a recent study in which we investigated comprehension in a set of stroke aphasic patients who did not show the expected advantage for HF words (Hoffman, Rogers et al., in press). The patients in question had deficits of *semantic control*: the executive regulation of semantic knowledge that is necessary to ensure retrieval of the appropriate semantic information in a particular situation or context (Badre & Wagner, 2002; Jefferies & Lambon Ralph, 2006; Noonan, Jefferies, Corbett, & Lambon Ralph, 2010; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). We predicted that comprehension of HF words would be particularly difficult for these patients because HF words tend to appear in a wide range of linguistic contexts associated with different semantic information. For example, the HF word *head* can be used to refer to a part of the body ("My head hurts"), the chief of a school or organisation ("Go and see the head"), the front of an object (“I’m at the head of the queue”) or, as a verb, to set off towards a destination (“I’ll head for home”). When the word *head* is encountered, aspects of meaning relating to all these uses may be activated and semantic control is necessary to constrain activation to those aspects of knowledge that are currently relevant. This control function is particularly important when the word appears in a weak or ambiguous context. In contrast, LF words may be associated with a more restricted set of linguistic contexts and so the relevant semantic information is likely to be similar whenever the word is encountered (e.g., *spinach* almost always occurs in the context of eating and cooking). To test these predictions, we developed a measure called *semantic diversity* that used latent semantic analysis (Landauer & Dumais, 1997) to estimate the degree of semantic variability among the contexts in which a word was used. Patients with semantic control deficits showed poorer comprehension of semantically diverse words, presumably because they are associated with a broad set of semantic information from diverse contexts. Importantly, HF words tended to have high semantic diversity values and this correlation was responsible for the “missing” frequency effect in the group. Once diversity values were controlled for statistically, comprehension of HF words was found to be significantly better than that of LF words.

The semantic diversity explanation holds that HF words have diverse contextual associations and are therefore processed poorly by patients with impaired semantic control, counteracting the expected HF word advantage. It also predicts that under sufficiently demanding circumstances, semantic control deficits will give rise to frequency effects that are not merely absent but are reversed outright. Here, we tested this hypothesis in two patients with established semantic control deficits. We employed a delayed word repetition task that maximised the likelihood of observing reverse frequency effects. There were a number of reasons for adopting this particular paradigm. First, though it does not involve an explicit semantic judgement, delayed word repetition is known to depend on maintenance of semantic information. Immediate repetition of single words can often be performed purely on the basis of their phonological structure. However, the stored phonological representation can be disrupted by inserting a delay between presentation and repetition in which the patient must produce speech (e.g., by counting aloud). In these circumstances, repetition depends to a much greater extent on activating and retaining the appropriate semantic representation (Jefferies, Crisp, & Lambon Ralph, 2006).

Second, words in this task were presented without any of the situational or linguistic context that would normally help to constrain semantic activation. Because HF words often depend on context for their interpretation, one would expect them to elicit a somewhat weak and unstable semantic representation under these circumstances, as aspects of meaning relating to many possible contexts would be activated. Maintaining this weak pattern of activation is likely to be difficult for patients who have difficulty regulating semantic knowledge. In contrast, because they appear in a narrower set of contexts, LF words tend to activate similar semantic information whenever they appear. LF words might therefore elicit a relatively strong, stable pattern of semantic activation even in the absence of context, posing fewer problems for the patients.

Finally, the delayed repetition paradigm is known to promote perseverative errors in aphasic patients, in which patients produce an earlier response in place of the current target word (Jefferies et al., 2006). Preservations are thought to occur when the activation of a previous response exceeds that of the target, either due to a failure to inhibit previous targets (Campbell & Arbuthnott, 1996) or due to weak processing of the current target (Gotts & Plaut, 2004; Martin & Dell, 2007). Perseverative errors can therefore be informative about the relative activation strengths of different words. If HF words elicited more robust and stable activation than LF words, as predicted by most models of language processing, perseverations would occur when weak activation of a LF target is exceeded by that of an earlier HF word. This pattern occurs when perseverations are elicited from healthy subjects in deadline naming tasks (Vitkovitch & Humphreys, 1991) and has been found in some aphasic patients (Gotts, della Rocchetta, & Cipolotti, 2002; Hirsh, 1998). Conversely, our approach specifically predicts a *negative* effect of frequency on perseverations in patients with impaired semantic control. Because we expected LF words to elicit stronger and more stable semantic activation than HF words, perseverations should occur when an earlier LF response interferes with the weak activation elicited by the HF target. We tested this prediction by alternating HF and LF trials, so as to maximise the competition between HF and LF words.

Patient Descriptions

LS was a 72 year-old male retired car mechanic who suffered a CVA six years prior to this study. MRI scan indicated a large lesion in frontal, temporal and parietal regions of the left hemisphere. This affected dorsolateral and ventrolateral prefrontal cortex (principally BA 9, BA 44 and BA 45), posterior middle and inferior temporal cortex as well as the posterior occiptotemporal area and angular gyrus. He was echolalic and presented with a severe verbal comprehension deficit. His speech was fluent but empty and characterised by semantic jargon and he was markedly perseverative. LS's perseverations in picture naming and reading were the subject of a previous study (Corbett, Jefferies, & Lambon Ralph, 2008). His perseverations were not influenced by lexical frequency but were reduced by verbal cues that boosted the activation of the target.

PG was a 61 year-old man who managed a successful architecture business until a left-hemisphere stroke seven years previously. No MRI scan was available but a radiologist's report of a CT scan performed shortly after the infarct indicates damage in the left frontal and capsular regions. PG's speech was less fluent than LS's and was characterised by frequent word-finding difficulties and reduced phrase length. He made occasional perseverative errors, though these were much less pronounced than observed in LS. In picture naming, his errors often consisted of LF responses (e.g., hammock → "igloo").

Both patients have participated in a number of previous studies in which their deficits have been linked to poor regulation of activation within the semantic system, such that they have difficulty activating task-relevant information and inhibiting irrelevant aspects of knowledge (e.g., Corbett, Jefferies, Ehsan, & Lambon Ralph, 2009; Hoffman, Jefferies, & Lambon Ralph, in press; Jefferies & Lambon Ralph, 2006; Noonan et al., 2010). Background neuropsychological data are shown in Table 1. Semantic processing was impaired in both cases: they failed verbal and non-verbal components of the Cambridge semantic battery (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000). Verbal comprehension was also assessed with a synonym judgement test. Both patients were impaired and neither showed an effect of word frequency. Repetition skills were more preserved, although LS' digit span fell slightly below the normal range and PG's nonword repetition was somewhat impaired. LS showed some additional deficits of visuospatial processing and both patients were impaired on two tests of non-verbal executive function, consistent with a general cognitive control impairment.

-Table 1 around here-

Method

We employed a delayed repetition task in which patients were presented with a single auditory word, repeated it immediately, counted aloud to a specified number and then attempted to recall the word. As explained in the Introduction, this task emphasises activation and maintenance of semantic representations and is known to induce perseverative errors in aphasic patients.

Materials: Two sets of stimuli were presented in separate testing sessions (see Appendix). Set A comprised 40 HF words with a mean frequency in the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993) of 888 counts per million (range = 501-1758) and

40 LF words (mean frequency = 4.4; range = 1-10). HF words had higher semantic diversity values than LF words, indicating that they tended to appear in a more disparate set of linguistic contexts (2.12 vs. 1.49; $t(75) = 10.9$, $p < 0.001$). In addition, HF words had a greater number of definitions in the Wordnet lexical database (9.70 vs. 3.65; $t(78) = 5.6$, $p < 0.001$). Stimulus selection was aided by the computer program Match (van Casteren & Davis, 2007), which enabled us to equate HF and LF words within each set almost perfectly for imageability, syllable and phoneme length and phonological neighbourhood size.

Set B was intended to replicate the findings from Set A whilst also controlling for word class. While some of HF words in Set A were function words, all 80 words in Set B were nouns (note, however, that in order to use the highest possible frequency words it was necessary to re-use some of the nouns from Set A). Mean frequency for HF words was 701 (range = 406-1980) and for LF words was 5.2 (range = 1-10). HF words again had higher semantic diversity values (2.03 vs. 1.44; $t(73) = 10.8$, $p < 0.001$) and more definitions (14.05 vs. 3.43; $t(78) = 6.0$, $p < 0.001$).

Procedure: HF and LF words were presented in an alternating fashion. On each trial, a single word was spoken by the experimenter and repeated immediately by the patient. Occasionally this initial repetition was incorrect and the word was presented again. This immediate repetition allowed us to confirm that any errors in the subsequent delayed repetition were not due to auditory perception or verbal production deficits. Following their initial repetition, the patient counted aloud from one to a specified number and then attempted to recall the word. We found that the patients varied from session to session in the length of delay needed to produce errors. The length of the counting delay was therefore determined at the start of each session based on a pilot test and was set at a level that avoided either ceiling or floor effects. LS was markedly perseverative in most verbal tasks and a short delay was used to avoid blanket perseveration. He was asked to count to 8 or 10 (which took between 3 and 5s). In contrast, PG perseverated only rarely in standard testing and a longer delay was necessary to elicit errors. PG was asked to count to 20 or 25 (12-15s).

Results

Figure 1 shows responses divided into correct recalls, perseverations and other errors. Considering overall accuracy, both LS and PG showed a reversal of the usual frequency effect in Set A, recalling more LF than HF words (LS: $\chi^2 = 5.2$, $p = 0.02$; PG: $\chi^2 = 5.6$, $p = 0.02$). A similar pattern was observed for Set B, although this failed to reach statistical significance for LS (LS: $\chi^2 = 2.7$, $p = 0.1$; PG: $\chi^2 = 5.2$, $p = 0.02$). Patients were more likely to perseverate when repeating HF words in Set A (LS: $\chi^2 = 6.3$, $p = 0.01$; PG: $\chi^2 = 9.0$, $p = 0.003$) and again the same trend in Set B was significant only for PG (LS: $\chi^2 = 2.1$, $p = 0.15$; PG: $\chi^2 = 5.2$, $p = 0.02$). Often, patients recalled a word correctly but on the subsequent trial produced it again (see Table 2 for examples). Of 22 such errors made by PG (collapsed across both sets), 21 involved a LF word being produced instead of a HF word and only once did a HF word replace a LF word. LS generated 26 such errors: 21 where the correct HF word was replaced by the previous LF word and only five where the reverse occurred. Both error patterns differed from the expected chance distribution (Binomial $p < 0.003$). Therefore, HF words were less likely to be recalled correctly and more likely to induce perseverative errors, but the words that were produced as perseverations were typically LF.

-Table 2 and Figure 1 around here-

Discussion

Though most models of language processing, as well as empirical data from healthy subjects, indicate that HF words are processed more efficiently than LF words, this effect is often absent in stroke aphasia. Moreover, in rare cases it is reversed such that LF words are processed more successfully (Crutch & Warrington, 2005; Marshall et al., 2001). Here, we used a delayed repetition task to reveal reverse frequency effects in two aphasic patients with semantic control deficits. These effects suggest that HF words place high demands on semantic control processes, potentially because they appear in a wide range of different contexts (Hoffman, Rogers et al., in press). Consequently, when encountered without any contextual constraints, a HF word activates a weak and unstable pattern of semantic activation that requires support from control and regulation processes if it is to remain active enough for subsequent retrieval. The strongest support for this claim came from analysing the perseverative errors of the patients. Perseverations occur when activation of a previously presented word exceeds that of the current target. Perseverations made by our patients almost always involved a LF word being produced in place of a HF target, confirming that the semantic activation associated with HF words was weaker and less stable than that elicited by LF words.

Attenuated frequency effects have also received attention in patients with refractory access disorders, in whom comprehension deteriorates when the same set of concepts are repeatedly probed at a fast rate (Warrington & Shallice, 1979). The lack of sensitivity to word frequency has been explained in these patients by positing that access to semantic representations is disrupted in a stochastic fashion, such that the success of accessing a particular word is not affected by its psycholinguistic properties (Warrington & Cipolotti, 1996). Although this account explains why patient would fail to show frequency effects at all, it provides no explanation for circumstances in which LF words are accessed/maintained *more* successfully than HF words. An alternative perspective is provided by Gotts and Plaut (2002), who have proposed that refractory access deficits are the result of damage to neuromodulatory mechanisms that prevent synaptic depression. On this view, HF words are initially activated more strongly than LF words, which makes them more susceptible to synaptic depression and more affected when depression is allowed to proceed unchecked. Gotts and Plaut simulated refractory access deficits in a connectionist computational model and demonstrated substantial reductions in the size of frequency effect as result of a neuromodulatory deficit. In theory, a sufficiently severe deficit of this kind might give rise to an outright reversal of the frequency effect. However, we note that such a reversal was never observed in Gotts and Plaut's simulations, even under the most severe levels of damage. So it is not clear at present whether the neuromodulatory model can account for the unusual effects presented here.

It is worth noting that frequency effects are not always absent in stroke aphasia, particular in studies of perseveration. These studies give a somewhat mixed picture, with some patients perseverating less often in response to HF targets (Gotts et al., 2002; Hirsh, 1998) while others show no impact of frequency (Ackerman & Ellis, 2007; Halpern, 1965). Additionally, when perseverations are induced in healthy subjects through speeded responding, they are less likely to occur for HF targets (Vitkovitch & Humphreys, 1991). We propose that differences in the cognitive demands of the tasks used and in the underlying deficits of the patients can account for these differences. On our view, reduced or reversed frequency effects would be expected in patients with semantic control deficits (e.g., Jefferies & Lambon Ralph, 2006). In contrast, patients with deficits to other components of the language system would not be expected to show the same sensitivity to control factors. Instead, they might show normal or exaggerated effects of frequency, due to positive influences of frequency on other elements of language processing. For example, patients with phonological deficits are likely to show positive frequency effects because the more familiar phonological forms of HF words lend them a processing advantage. In fact, when we tested a series of phonologically-impaired stroke patients on the same delayed repetition task, they showed a positive frequency effect in accuracy and in perseverations, unlike the patients described here (Jefferies et al., 2006). Task differences may also explain why reverse frequency effects have not been found previously in studies of perseveration. Previous studies have used picture naming or word reading tasks (e.g., Gotts et al., 2002). In these tasks, the phonological form of the word is accessed from semantics or orthography, a process that is more efficient for HF words (e.g., Plaut et al., 1996). In our task, phonology was initially supplied by the experimenter and the key requirement was to activate and maintain the appropriate semantic representation. We also presented stimuli in an alternating fashion to maximise the difference in activation level between the current and previous trial, whereas other studies have presented blocks of HF and LF words. We suspect that a combination of the appropriate patients, task and stimuli were necessary to reverse the strong processing advantage usually available to HF words. The fact that the frequency effect *can* be reversed in this way suggests that, for patients with semantic control deficits, being high in frequency is actively detrimental to performance.

References

Ackerman, T., & Ellis, A. W. (2007). Case study: Where do aphasic perseverations come from? *Aphasiology, 21*(10-11), 1018-1038.

Adelman, J. S., Brown, G. D. A., & Quesada, J. F. (2006). Contextual diversity, not word frequency, determines word-naming and lexical decision times. *Psychological Science, 17*(9), 814-823.

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1993). *The CELEX lexical database (CD-ROM)*. Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania.

Badre, D., & Wagner, A. D. (2002). Semantic retrieval, mnemonic control, and prefrontal cortex. *Behavioral and Cognitive Neuroscience Reviews, 1*, 206-218.

Balota, D. A., & Chumbley, J. I. (1984). Are Lexical Decisions a Good Measure of Lexical Access - the Role of Word-Frequency in the Neglected Decision Stage. *Journal of Experimental Psychology-Human Perception and Performance, 10*(3), 340-357.

Bozeat, S., Lambon Ralph, M. A., Patterson, K., Garrard, P., & Hodges, J. R. (2000). Non-verbal semantic impairment in semantic dementia. *Neuropsychologia, 38*(9), 1207-1215.

Campbell, J. I. D., & Arbuthnott, K. D. (1996). Inhibitory processes in sequential retrieval: Evidence from variable-lag repetition priming. *Brain and Cognition, 30*(1), 59-80.

Corbett, F., Jefferies, E., Ehsan, S., & Lambon Ralph, M. A. (2009). Different impairments of semantic cognition in semantic dementia and semantic aphasia: Evidence from the non-verbal domain. *Brain, 132*, 2593-2608.

Corbett, F., Jefferies, E., & Lambon Ralph, M. A. (2008). The use of cueing to alleviate recurrent verbal perseverations: Evidence from transcortical sensory aphasia. *Aphasiology, 22*, 363-382.

Crutch, S. J., & Warrington, E. K. (2005). Abstract and concrete concepts have structurally different representational frameworks. *Brain, 128*, 615-627.

Dell, G. S. (1989). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. In W. Marslen Wilson (Ed.), *Lexical representation and process*. Cambridge, MA: MIT Press.

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12*, 627-635.

Gotts, S. J., della Rocchetta, A. I., & Cipolotti, L. (2002). Mechanisms underlying perseveration in aphasia: evidence from a single case study. *Neuropsychologia, 40*(12), 1930-1947.

Gotts, S. J., & Plaut, D. C. (2002). The impact of synaptic depression following brain damage: A connectionist account of "access/refractory" and "degraded-store" semantic impairments. *Cognitive, Affective, & Behavioral Neuroscience, 2*(3), 187-213.

Gotts, S. J., & Plaut, D. C. (2004). Connectionist approaches to understanding aphasic perseveration. *Seminars in Speech and Language, 25*, 323-334.

Halpern, H. (1965). Effect of stimulus variables on verbal perseveration of aphasic subjects. *Perceptual and Motor Skills, 20*, 421-429.

Hirsh, K. W. (1998). Perseveration and activation in aphasic speech production. *Cognitive Neuropsychology, 15*(4), 377-388.

Hoffman, P., Jefferies, E., & Lambon Ralph, M. A. (in press). Ventrolateral prefrontal cortex plays an executive regulation role in comprehension of abstract words: Convergent neuropsychological and rTMS evidence. *Journal of Neuroscience*.

Hoffman, P., Rogers, T. T., & Lambon Ralph, M. A. (in press). Semantic diversity accounts for the “missing” word frequency effect in stroke aphasia: Insights using a novel

method to quantify contextual variability in meaning. *Journal of Cognitive Neuroscience*.
Hulme, C., Roodenrys, S., Schweickert, R., Brown, G. D. A., Martin, S., & Stuart, G. (1997). Word-frequency effects on short-term memory tasks: evidence for a redintegration process in immediate serial recall. *Journal of Experimental Psychology: Learning, Memory and Cognition, 23*(5), 1217-1232.
Jefferies, E., Baker, S. S., Doran, M., & Lambon Ralph, M. A. (2007). Refractory effects in stroke aphasia: A consequence of poor semantic control. *Neuropsychologia, 45*, 1065-1079.
Jefferies, E., Crisp, J., & Lambon Ralph, M. A. (2006). The impact of phonological or semantic impairment on delayed auditory repetition: Evidence from stroke aphasia and semantic dementia. *Aphasiology, 20*, 963-992.
Jefferies, E., & Lambon Ralph, M. A. (2006). Semantic impairment in stroke aphasia vs. semantic dementia: A case-series comparison. *Brain, 129*, 2132-2147.
Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction and representation of knowledge. *Psychological Review, 104*, 211-240.
Marshall, J., Pring, T., Chiat, S., & Robson, J. (2001). When ottoman is easier than chair: An inverse frequency effect in jargon aphasia. *Cortex, 37*(1), 33-53.
Martin, N., & Dell, G. S. (2007). Common mechanisms underlying perseverative and non-perseverative sound and word substitutions. *Aphasiology, 21*(10-11), 1002-1017.
Nelson, D. L., & McEvoy, C. L. (2000). What is this thing called frequency? *Memory & Cognition, 28*(4), 509-522.
Nickels, L., & Howard, D. (1995). Aphasic naming: What matters? *Neuropsychologia, 33*(10), 1281-1303.
Noonan, K. A., Jefferies, E., Corbett, F., & Lambon Ralph, M. A. (2010). Elucidating the nature of deregulated semantic cognition in semantic aphasia: Evidence for the roles of the prefrontal and temporoparietal cortices. *Journal of Cognitive Neuroscience, 22*, 1597-1613.
Oldfield, R. C. (1966). Things, words and the brain. *Quarterly Journal of Experimental Psychology, 18*, 3-16.
Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*(1), 56-115.
Reder, L. M., Anderson, J. R., & Bjork, R. A. (1974). Semantic interpretation of encoding specificity. *Journal of Experimental Psychology, 102*, 648-656.
Rogers, T. T., & McClelland, J. L. (2004). *Semantic cognition: A parallel distributed processing approach*. Cambridge, MA: MIT Press.
Stemberger, J. P. (1985). An interactive activation model of language production. In A. W. Ellis (Ed.), *Progress in the psychology of language production* (Vol. 1). London: Lawrence Erlbaum Associates Ltd.
Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences of the United States of America, 94*, 14792-14797.
van Casteren, M., & Davis, M. H. (2007). Match: A program to assist in matching the conditions of factorial experiments. *Behavior Research Methods, 39*(4), 973-978.
Vitkovitch, M., & Humphreys, G. W. (1991). Perseverant Responding in Speeded Naming of Pictures - Its in the Links. *Journal of Experimental Psychology-Learning Memory and Cognition, 17*(4), 664-680.

Warrington, E. K., & Cipolotti, L. (1996). Word comprehension: The distinction between refractory and storage impairments. *Brain, 119*, 611-625.
Warrington, E. K., & Shallice, T. (1979). Semantic access dyslexia. *Brain, 102*(MAR), 43-63.

Table 1: Background neuropsychological tests

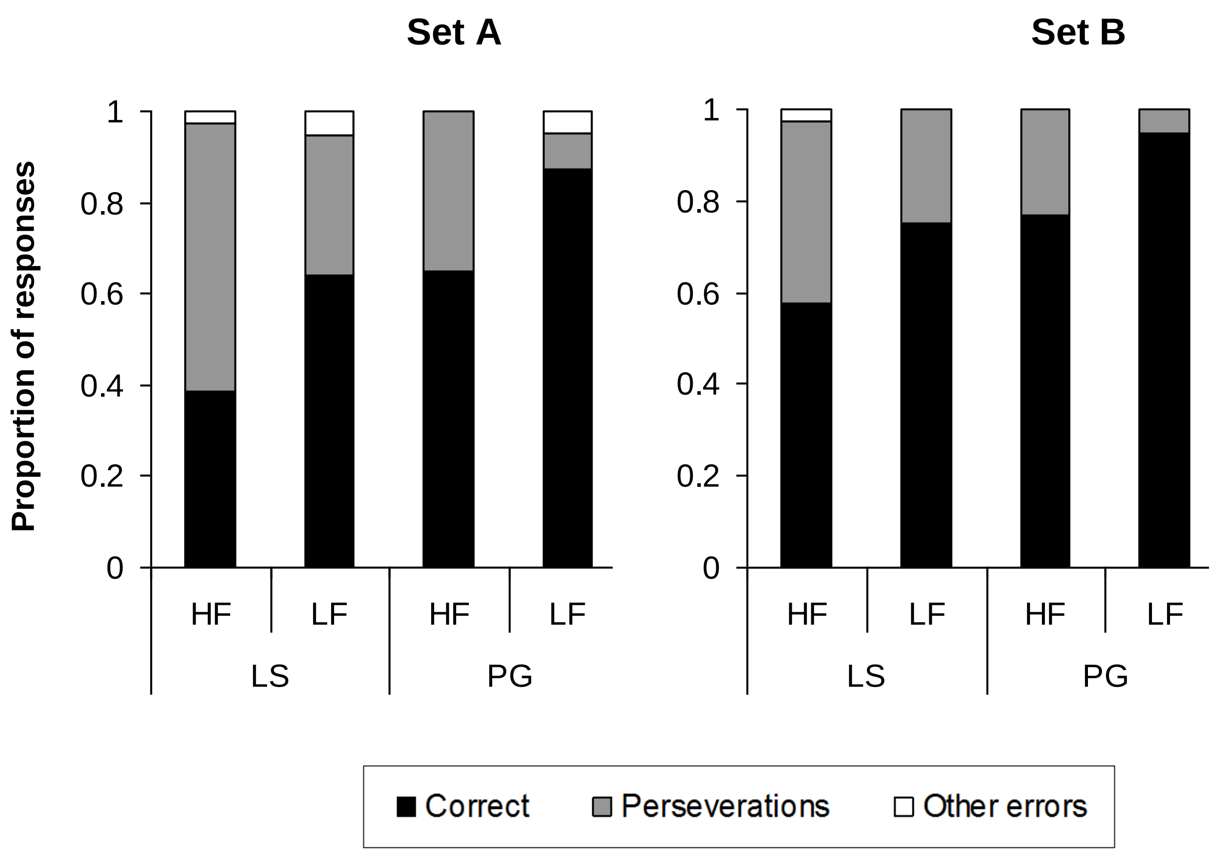
	Test	Max	LS	PG	Controls Mean	s.d.
Semantic	Picture naming	64	5*	44*	62.3	1.6
	Spoken word-picture matching	64	37*	58*	63.7	0.5
	Camel and Cactus Test					
	Pictures	64	15*	44*	59.0	3.1
	Words	64	16*	40*	60.7	2.1
	Category fluency (8 categories)	-	13*	7*	113.9	12.3
	Synonym Judgement					
	High frequency words	48	22*	34*	47.1	1.0
	Low frequency words	48	27*	35*	47.4	1.0
Repetition	PALPA 9 word repetition	80	77*	73*	-	-
	PALPA 8 nonword repetition	30	27*	22*	-	-
	Digit span					
	Forwards	-	4*	6	6.8	0.9
	Backwards	-	1*	2*	4.7	1.2
Visuospatial	Rey figure copy	36	19.5*	36	34.0	2.9
	VOSP					
	Incomplete letters	20	0*	18	19.2	0.8
	Dot counting	10	6*	5*	9.9	0.3
	Position discrimination	20	16*	20	19.8	0.6
	Cube analysis	10	4*	10	9.7	2.5
Executive	Coloured progressive matrices	-	16	23	>15	
/Attention	Wisconsin card-sorting task	6	0*	0*	>1	
	Brixton spatial rule attainment task	55	14*	26*	>28	

* denotes abnormal scores.

Table 2: Examples of responses

Trial	Condition	Presented Word	LS immediate repetition	LS delayed repetition	PG immediate repetition	PG delayed repetition
1	LF	Hawk	Hawk	Hawk	Hawk	Hawk
2	HF	Face	Face	Hawk	Face	Hawk
3	LF	Beak	Beak	Beak	Beak	Beak
4	HF	Time	Time	Time	Time	Time
5	LF	Shale	Shale	Shale	Shale	Shale
6	HF	End	End	Shained	End	Shale
7	LF	Spout	Spout	Spout	Spout	Spout
8	HF	Night	Night	Smite	Night	Spout
9	LF	Zeal	Zeal	Zeal	Zeal	Zeal
10	HF	Thing	Thing	Zeal	Thing	Zeal

Figure 1: Correct Responses, Perseverations and Other Errors



HF = high frequency trial; LF = low frequency trial.

Appendix: Experimental Stimuli

Set A

High frequency: against, always, because, become, country, end, even, every, face, good, hand, head, help, himself, house, kind, last, late, little, live, long, look, man, never, once, only, people, point, problem, school, sit, these, thing, try, under, well, without, woman, work, year

Low frequency: agile, alias, beak, bin, cache, canteen, chic, clearance, despot, fervour, gem, glut, halve, haste, hawk, hound, jeer, lard, lawful, maple, meek, morass, nadir, noun, numb, outset, ram, rogue, saga, scornful, smack, snort, spook, spool, stale, thud, usurp, wallet, worse, zeal

Set B

High frequency: book, case, child, country, end, face, fact, family, form, girl, group, hand, head, home, house, kind, life, light, man, mother, night, number, part, party, people, place, point, problem, question, room, school, side, thing, time, water, week, woman, work, world, year

Low frequency: beak, bib, bin, broom, bunny, canteen, coke, conquest, crab, crock, dime, disgrace, foal, fraud, gem, gust, hawk, haze, hound, lair, lime, mirage, petal, prong, pup, rhyme, sap, shale, shawl, siren, sod, spool, spout, stripe, thud, veal, vine, wallet, zeal, zipper