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Comprehension of concrete and abstract words in semantic dementia

Elizabeth Jefferies[a,*], **Karalyn Patterson**[b], **Roy W. Jones**[c], and **Matthew A. Lambon Ralph**[d]

[a]University of York, UK

[b]MRC Cognition and Brain Sciences Unit, Cambridge

[c]RICE – Research Institute for the Care of Older People, Royal United Hospital, Bath, UK

[d]University of Manchester, UK

Abstract

The vast majority of brain-injured patients with semantic impairment have better comprehension of concrete than abstract words. In contrast, several patients with semantic dementia (SD), who show circumscribed atrophy of the anterior temporal lobes bilaterally, have been reported to show *reverse* imageability effects, i.e., relative preservation of abstract knowledge. Although these reports largely concern individual patients, some researchers have recently proposed that superior comprehension of abstract concepts is a characteristic feature of SD. This would imply that the anterior temporal lobes are particularly crucial for processing sensory aspects of semantic knowledge, which are associated with concrete not abstract concepts. However, functional neuroimaging studies of healthy participants do not unequivocally predict reverse imageability effects in SD because the temporal poles sometimes show greater activation for more abstract concepts. We examined a case-series of eleven SD patients on a synonym judgement test that orthogonally varied the frequency and imageability of the items. All patients had higher success rates for more imageable as well as more frequent words, suggesting that (a) the anterior temporal lobes underpin semantic knowledge for both concrete and abstract concepts, (b) more imageable items – perhaps due to their richer multimodal representations – are typically more robust in the face of global semantic degradation and (c) reverse imageability effects are not a characteristic feature of SD.

Keywords

semantic dementia; imageability; concreteness; anterior temporal; synonym judgement

Introduction

How do we represent and process the meanings of concrete and abstract words such as COAT and HOPE? Concrete concepts encapsulate the meanings of tangible things that can be experienced through our senses – consequently, we can readily form mental images for concrete words. Abstract concepts, in contrast, do not refer to physical objects and, for the most part,

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*Correspondence to: Dr. Elizabeth Jefferies, Department of Psychology, University of York, Heslington, York, YO10 5DD, UK, Tel: +44 (0) 1904 434368, ej514@york.ac.uk.

do not readily evoke mental images: instead these concepts refer to ideas or mental states. In behavioural studies, healthy participants often show faster and more accurate processing for imageable words (DeGroot, 1989; James, 1975; Kroll & Merves, 1986; Paivio, 1991). Patients with brain-damage normally show an exaggeration of this effect – for example, people with aphasia and deep dyslexia typically make many more errors for abstract than concrete items (Coltheart, 1980; Goodglass et al., 1969; Jefferies et al., 2007). However, in a small number of neuropsychological cases, *reverse* imageability effects have been observed; i.e., relative preservation of abstract knowledge (Breedin et al., 1994; Cipolotti & Warrington, 1995; Reilly et al., 2006; Sirigu et al., 1991; Warrington, 1975; Yi et al., 2007). Most of the patients showing this pattern have had damage to the anterior temporal lobes (ATL) bilaterally, typically due to herpes simplex encephalitis or semantic dementia (Marshall et al., 1996, excepted).

This double dissociation suggests that the cognitive and neural organisation of concrete and abstract concepts may be partially distinct. Concrete items have sensory referents, whereas abstract items do not (Paivio, 1986). Visual and other sensory processes may therefore contribute to semantic knowledge for concrete concepts, resulting in more semantic features/ richer semantic representations for these items (Paivio, 1986; Plaut & Shallice, 1993). This notion is supported by the fact that people can generate more predicates for imageable words (Jones, 1985). In contrast, abstract concepts might be more dependent on linguistic processes, given that the meaning of these items is strongly affected by sentence context (e.g., Schwanenflugel & Shoben, 1983).

According to these proposals, reverse imageability effects could result from damage to visual (and possibly other sensory) aspects of semantic knowledge. Consequently, the brain regions damaged in semantic dementia (SD) might play a particularly important role in visual/sensory knowledge of objects. Patients with SD have relatively circumscribed bilateral atrophy of the anterior and inferior aspects of the ATL, and the extent of this atrophy correlates with the severity of the semantic impairment (Mummery et al., 2000; Nestor et al., 2006). This pattern of brain damage results in a highly specific impairment of semantic memory: other aspects of cognition and language such as phonology, visual processing and decision-making remain largely intact (Hodges et al., 1992; Snowden et al., 1989). The semantic impairment in SD affects the full range of input and output modalities – including spoken and written words, pictures, real objects, environmental sounds, smells and touch (Bozeat et al., 2000; Coccia et al., 2004; Luzzi et al., 2007). There is also a significant degree of item-specific consistency when the same items are probed using different semantic tasks (Bozeat et al., 2000; Coughlan & Warrington, 1981). These findings indicate that the semantic impairment in SD is *amodal* and not specific to either verbal or non-verbal information (Rogers et al., 2004). The anterior temporal lobes are a plausible substrate for forming amodal semantic representations as they have extensive connections with cortical areas that represent modality-specific information (see also the theory of "convergence zones"; A. R. Damasio, 1989; H. Damasio et al., 2004; Gloor, 1997). Accordingly, Rogers et al. (2004) implemented a computational model of the ATL semantic system in which semantic representations were formed through the distillation of information required for mappings between different verbal and non-verbal modalities. When the model was damaged, it reproduced the deficits shown by SD patients across different input and output modalities.

Although patients with SD show *generalised* semantic degradation, there is also evidence to suggest that they have relatively poor knowledge of sensory attributes compared to functional information (though both are markedly impaired). Patients' definitions of pictures and words contain more associative/functional content than sensory/physical information (Lambon Ralph et al., 1999; 2003; McCarthy & Warrington, 1988). A similar pattern was found for an individual patient studied by Cardebat et al. (1996) who was unable to draw animals and objects from memory despite producing some functional properties. Moreover, SD patients show poorer definition-to-picture matching when given descriptions that contain sensory rather than functional information (Lambon Ralph et al., 2003). The inferior temporal lobes are thought to underpin the ‘ventral visual stream’, which allows object recognition (Ungerleider & Mishkin, 1982). Given that the focus of atrophy in SD is in anterior, inferior temporal lobes, it is possible that the damaged cortex makes a greater contribution to sensory aspects of semantic knowledge than to functional/associative semantic properties.

If visual/sensory properties are especially vulnerable to damage in SD, we might expect these patients to have more pronounced deficits for imageable than abstract concepts. As noted above, some cases with SD have shown precisely this pattern – i.e., reverse imageability effects in semantic tasks (Breedin et al., 1994; Cipolotti & Warrington, 1995; Papagno et al., 2007; Reilly et al., 2007a; [2006]; 2007b; Vesely et al., 2007; Warrington, 1975; Yi et al., 2007). A recent review suggested that better comprehension of abstract than concrete concepts is one of the general features of SD (Grossman & Ash, 2004). It is important to emphasise, however, that reverse imageability effects have been reported in a relatively small number of studies, which have largely examined single cases. It is therefore unclear whether reverse imageability effects are the norm in SD, or whether there is a reporting bias. At least some, though not all, of the reports of patients with reverse imageability effects were accompanied by lesion information implicating the ATL – but this does not establish that ATL lesions *predictably* produce reverse imageability effects. A recent study did find poorer comprehension of motion verbs compared with cognition verbs in a group of twelve patients with SD, although this effect was not found for nouns in the same definition-to-word matching task (Yi et al., 2007) (see also Reilly et al., 2007a). Moreover, a recent study by Pulvermüller et al. (2008) found *poorer* performance in a lexical decision task for abstract vs. concrete words in eight out of eleven SD patients. Crutch and Warrington (2006) also found that comprehension of abstract concepts was impaired in SD although frequency-matched abstract and concrete concepts were not compared. Therefore, additional research is needed to establish if reverse imageability effects are widespread in SD.

Functional neuroimaging studies of neurologically intact participants also provide relevant evidence about the neural organisation of concrete and abstract concepts. These studies point to considerable overlap in the network representing abstract/imageable words, although some differences have also been observed. Figure 1 shows sites of peak atrophy and hypometabolism in SD (in yellow) together with peak activations from functional neuroimaging studies that directly contrasted concrete (C) and abstract (A) words. This meta-analysis shows that although *individual* functional neuroimaging studies might be taken as evidence for the importance of the ATL in concrete or abstract concepts, the pattern across studies is inconsistent. Temporal lobe sites showing greater activation for C>A words (in blue/cyan) have almost exclusively been found within occipital, posterior inferotemporal cortex (shown on slices Y=−51 and Y=−41) and medial ATL sites (Y=−21; Y=−11, including one peak in left inferior temporal pole (slice Y=19) (Fiebach & Friederici, 2003;Noppeney & Price, 2002;Sabsevitz et al., 2005;Whatmough et al., 2004;Wise et al., 2000). Meanwhile, sites showing greater activation for A>C words (in red/pink) occurred in more diverse areas linked to language processing, especially left posterior superior temporal areas (including the superior parts of the temporal poles bilaterally; shown on slices Y=9 and Y=19) and left inferior frontal gyrus (Y=9, Y=19) (Binder et al., 2005;Kiehl et al., 1999;Noppeney & Price, 2004;Perani et al., 1999;Sabsevitz et al., 2005;Whatmough et al., 2004). These patterns are broadly consistent with the proposal that concrete concepts are more reliant on occipital-temporal areas that underpin visual object recognition (Ungerleider & Mishkin, 1982), while abstract concepts depend more on brain regions responsible for verbal comprehension (e.g., Scott et al., 2000). However, the functional neuroimaging findings do not unequivocally predict reverse imageability effects in SD. As revealed by Figure 1, SD patients show atrophy and hypometabolism across the ATL, affecting both superior temporal pole areas that might be particularly critical for abstract words and medial ATL regions that might play a greater role in processing concrete words. Moreover, there is considerable overlap in the areas activated by C and A concepts in the ATL. Of the twelve studies reviewed here (see Figure 1 for details), ATL activation (Y>−4) was observed in five studies for A>C and two studies for C>A, suggesting a high level of inconsistency and substantial numbers of null results. From this, we would expect the overwhelming majority of SD patients to show substantial deficits for both concrete and abstract items. Furthermore, given that normal language users tend to reveal a C>A advantage in many tasks, we predict that, as comprehension deteriorates in SD, it will largely maintain this C>A profile. On this account, the reported SD cases showing A>C would be occasional deviations from the typical pattern.

The current study examined this issue by assessing the comprehension of concrete and abstract words in a case-series of eleven patients. Our sample should be unaffected by the “reporting bias” discussed above (i.e., the tendency to selectively publish case reports that show reverse concreteness effects), because the patients were selected *only* on the basis that they had a diagnosis of SD and were available for testing. The patients ranged in severity from mild to severe, allowing an investigation of the relationship between the degree of semantic impairment and the size of any difference between abstract and concrete words. More severely impaired cases might be less likely to reveal a difference in either direction because the atrophy in SD spreads as the disease progresses. We used a synonym judgement task that orthogonally varied the frequency and imageability of the items. Word frequency was manipulated as well as imageability for two reasons. First, this allowed the test to be sensitive to imageability effects in both mild and severely impaired cases (avoiding floor and ceiling effects). Secondly, the frequency findings are of interest in their own right. Although the meanings of frequently encountered words/pictures are reported to be better preserved than less frequent stimuli in SD, this work is limited to picture naming (Lambon Ralph et al., 1998), regression analyses of comprehension tasks (Bozeat et al., 2000) and single case-studies (Funnell, 1995).

As well as addressing these theoretical considerations, this paper also has a practical motivation: we publish a new synonym test which has some advantages over the existing alternatives. (1) The test examines the influence of imageability and frequency at the same time. These factors are varied orthogonally so that interactions between them can be investigated. (2) The test includes substantial variation of both of these variables. (3) Frequency and imageability are manipulated for the response choices as well as for the probe words, increasing the sensitivity of the test to these effects. (4) There are three rather than the usual two response choices per trial, reducing the chance rate from 0.5 to 0.33.

Method

Test construction

There were 96 trials split evenly between two frequency bands (mean frequency of probe words (with standard deviations in parentheses) = 128 (102) and 4.6 (4.5) counts per million in the Celex database; Baayen et al., 1993) and three imageability bands (mean imageability of probe words = 275 (17.3), 452 (26.0) and 622 (14.0) respectively, on a scale of 100–700, from the MRC Psycholinguistic Database; Coltheart, 1981). The frequency ranges of the high/low frequency sets did not overlap, and similarly, the high, medium and low imageability words had non-overlapping imageabilities. Frequency and imageability were varied orthogonally; there were sixteen trials in each of the six frequency-by-imageability conditions. Frequency was matched in triplets across the high, medium and low imageability words, and imageability was matched pairwise for the high and low frequency sets. Target words (i.e., the intended correct choice) were presented alongside two unrelated distracters. Both the targets and distracters were matched to the probe word for frequency and imageability. As a consequence, imageability and frequency were varied in the trial as a whole. The conditions were not matched for word length (average = 5.6, 6.5 and 7.7 letters per word for the high, medium and low imageability conditions respectively). Simultaneous auditory and visual presentation was used and patients indicated their choice by pointing. The test was not timed. The items are provided in supplemental material published online.

Participants

The synonym judgement task was administered to eleven patients with a clinical diagnosis of SD, recruited from Cambridge, Bath or Liverpool, UK. IRB approval was provided by a Multi-Centre Research Ethics Committee (covering patients in Bath and Liverpool) and the Cambridgeshire Research Ethics Committee. The patients fulfilled all of the published criteria for SD (e.g., Hodges et al., 1992): they had word-finding difficulties in the context of fluent speech and showed impaired semantic knowledge and single word comprehension; in contrast, phonology, syntax, visual-spatial abilities and day-to-day memory (assessed informally in conversation) were relatively well preserved. Table 1 provides demographic details and background neuropsychological scores on tasks administered periodically as part of our standard battery of assessments. All of the scores were obtained within a year of the synonym judgement task. MRI revealed focal atrophy of the anterior temporal lobes bilaterally in every case.

Eleven healthy participants matched in age to the SD group (age range 56 to 65) also completed the synonym judgement task. They had an average of 15.3 years of education. There was no relationship between educational level and synonym judgement performance (for either the controls or the patients). All of the participants (patients and controls) provided written consent.

Results

The results of the synonym judgement test are shown in Figure 2. The SD patients performed substantially more poorly than controls in every condition ($t(20) = 9.6–2.3$, $p < .04$; Cohen's $d = 1.2–4.2$). The control group showed a positive effect of higher imageability ($F(2,20) = 7.2$, $p = .004$; partial Eta squared ($\eta_p^{\ 2}$) = .42) although performance was near ceiling on all conditions (there was no main effect of frequency and no interaction). The SD patients' comprehension showed strong positive effects of both higher imageability ($F(2,20) = 25.3$, $p < .0001$; $\eta_p^{\ 2} = .72$) and higher frequency ($F(1,10) = 62.6$, $p < .0001$; $\eta_p^{\ 2} = .86$). The interaction between these factors approached significance ($F(2,20) = 2.9$, $p = .08$; $\eta_p^{\ 2} = .22$). For *high frequency* items, medium imageability words were understood better than low imageability words (Bonferroni $t(10) = 4.7$, $p = .004$) but there was no advantage for high over medium imageability words ($t(10) < 1$). For *low frequency* items, accuracy was significantly greater for high vs. medium imageability words (Bonferroni $t(10) = 4.0$, $p = .01$) but the difference between medium and low imageability words did not reach significance ($t(10) = 1.9$, *n.s.*). These patterns of significance can be interpreted as follows: (1) Frequent words are understood comparatively well by patients with SD so their performance was only affected by the other variable – imageability – when it reached its lowest value. (2) SD patients are so poor at comprehending low-frequency words that their performance had already dropped to a low level for medium-imageability words; it declined further (essentially to chance) for the lowest value of imageability, but there was no room for this decrease to reach statistical significance.

Every individual SD patient showed better comprehension of high than low frequency words (Fisher exact one-tailed $p = .06$ to $< .0001$; Cramer's $V = .18–.64$; see Table 2). The majority of the SD group also demonstrated significantly better comprehension of the more imageable words (9/11 patients; Fisher exact two-tailed $p = .05$ to $< .0001$; Cramer's $V = .24–.47$). Two cases, GE and KI, who did *not* show significant positive effects of imageability were investigated in more detail. GE's performance was at ceiling for high frequency words and at floor for low frequency words, regardless of imageability. He was therefore tested on an additional set of medium frequency items to avoid floor and ceiling effects. On these items there was a significant positive effect of imageability (high imageability = 15/16 correct; medium imageability = 11/16; low imageability = 7/16; Fisher's exact two-tailed $p = .01$; Cramer's $V = .44$). The other exception was patient KI, who showed only a non-significant trend towards better performance for more imageable items on the original test. When KI was retested approximately a month later, his performance revealed a clear imageability advantage (high imageability = 27/32 correct; medium imageability = 19/32; low imageability = 14/32 collapsing across frequency; Fisher's exact twotailed $p = .003$). The imageability effect remained significant when the data from the two test sessions were combined ($p = .02$; Cramer's $V = .20$). We can therefore conclude that all eleven patients showed better comprehension of more imageable words. Reverse imageability effects were absent from the group.

To examine whether comprehension differences between abstract and concrete words varied with the severity of SD, a composite semantic score was derived from the background semantic tests available for all cases (picture naming, word-picture matching, Pyramids and Palm Trees test for pictures and category fluency; see Table 1). This showed a significant positive correlation with overall synonym judgement performance ($r = .66$, one-tailed $p = .01$) and with five of the six individual frequency/imageability conditions ($r = .54$ to $.76$, one-tailed $p < .05$); the one exception was the high frequency, high imageability condition which was prone to ceiling effects. There was no relationship between the severity of the semantic impairment and the size of frequency/imageability effects (as measured by the difference between these conditions). In addition, there was no correlation between educational level and any aspect of synonym judgement performance in SD – including accuracy in each condition and the magnitude of frequency/imageability effects.

Discussion

This study examined the impact of word frequency and imageability on synonym judgement in a case-series of eleven patients with semantic dementia (SD). Every case showed significantly better comprehension of high than low imageability words, along with more intact understanding of high compared with low frequency words. We did not observe a single instance of the *reverse* imageability effect reported previously for a few individual SD patients. In addition, there was no relationship between the degree of semantic impairment and the size of the imageability effect. Although the majority of patients showing relative preservation of abstract concepts to date have had damage to the ATL bilaterally, either in the context of SD or herpes simplex encephalitis, these studies have mostly examined single cases that were presumably selected because of the interesting nature of their semantic impairment. Investigations of single cases cannot resolve the question of whether ATL lesions *consistently* produce reverse imageability effects. Our case-series study of eleven patients indicates that, contrary to the suggestion that reverse imageability effects may be the norm in SD (Grossman & Ash, 2004), the *typical* pattern in SD is an advantage for concrete or high-imageability concepts. The impression of an association between SD and reverse imageability effects in the literature is likely to result from a reporting bias.

The marked frequency effect observed here fits with all known research on SD; it is mainly noteworthy because it is perhaps the clearest demonstration so far of the impact of this variable on performance in a receptive task, rather than the expressive tasks (such as object naming, reading, past-tense verb generation, etc) in which frequency effects have been amply documented in SD (e.g., Funnell, 1995; Lambon Ralph et al., 1998; Patterson et al., 2006; Woollams et al., 2007). More frequently encountered items are thought to form stronger semantic representations than less frequent ones, making them less vulnerable to degradation in SD (Rogers & McClelland, 2004). Other factors might also contribute to this effect, however; frequent concepts are typically acquired at an earlier age and continue to be encountered regularly as the semantic system degrades. This continued exposure may also afford them some protection from degradation in SD (see Lambon Ralph et al., 1998).

The marked positive imageability effect is more newsworthy because it clearly contradicts previous suggestions that reverse effects of imageability are the norm in this group. Our findings are inconsistent with the idea that the ATL is strongly specialised for visual aspects of knowledge. Instead, this brain region appears to underpin a single semantic store that is critical for understanding all types of stimuli, both concrete and abstract. Abstract words might have fewer semantic features and/or more impoverished semantic representations than imageable words (Paivio, 1986; Plaut & Shallice, 1993). Healthy participants are able to generate more predicates for imageable words, suggesting that these items have richer semantic representations (Jones, 1985). Even the control participants in this study revealed some benefit in choosing synonyms for high-imageability words. The outcome for the SD patients was therefore just an extension of the normal pattern. If the idea of richer, more detailed representations for concrete concepts is plausible, then it is also plausible that – as semantic memory deteriorates – the amount of information necessary to perform the forced-choice synonym judgement task will drop below ‘threshold’ sooner for abstract than for concrete concepts.

Our finding that SD patients were impaired at both concrete and abstract concepts is broadly consistent with neuroimaging studies that have found overlapping activation for these items within the ATL. It is important to note, however, that patient and neuroimaging studies provide rather different information about the neural basis of conceptual knowledge. The current neuropsychological investigation suggests that the ATL plays a *critical* role in abstract as well as concrete knowledge; however, we cannot rule out the possibility of functionally dissociable regions within this region (e.g., medial vs. superior ATL for concrete and abstract concepts respectively). Moreover, functional neuroimaging studies show widespread and partially distinct areas of brain activation for concrete and abstract items *beyond* the ATL, indicating that the wider neural networks that support these functions may be different. Transcranial magnetic stimulation (TMS) in healthy volunteers may provide a means of establishing which specific areas (a) within ATL and (b) beyond ATL are critical for understanding abstract and concrete concepts (Pobric et al., submitted).

Given our findings, how is one to understand the published reports of an abstractness advantage in a few patients with ATL lesions? There are at least two possibilities. First, whilst the temporal pole forms amodal representations of concepts by interacting with modality-specific areas devoted to sights, sounds, words, smells, touch etc., there might be some specialisation in areas of the temporal lobe as these inputs come together. The meta-analysis of neuroimaging studies shown in Figure 1 partially supports this view. There are peak activations for the abstract > concrete contrast all the way along the superior aspects of the temporal lobes. Previous research has shown that superior temporal cortex underpins speech comprehension, with more anterior areas responding only to intelligible speech and posterior areas uninfluenced by intelligibility (Crinion et al., 2003;Davis & Johnsrude, 2003;Narain et al., 2003;Scott et al., 2000). Superior temporal cortex might show greater activation for abstract words, at least in some studies, because these stimuli are highly reliant on this verbal comprehension pathway. In contrast, temporal lobe peaks for the concrete > abstract comparison fall within inferior and medial temporal cortex, amongst other areas. Similar regions are activated by visual object recognition (Kellenbach et al., 2005;Stewart et al., 2001), mental imagery (D'Esposito et al., 1997) and picture-based semantic tasks (Adams & Janata, 2002;Bright et al., 2004;Vandenberghe et al., 1996). One possibility, therefore, is that reverse concreteness effects occur in patients with an unusual distribution of ATL atrophy – for example, in cases with relative sparing of superior aspects of the ATL despite pronounced damage to medial temporal structures, or following the spread of atrophy to more posterior areas of inferior temporal cortex (especially in cases with only a mild degree of ATL atrophy). Further comparative studies of patients with different distributions of temporal lobe damage are required to test this atrophy-distribution hypothesis.

A second possibility is that individual differences in education, interests and experiences may substantially change the relative frequency with which concrete and abstract words are encountered and produced by patients premorbidly and/or during the course of the disease. At least some of the SD cases who have shown reverse concreteness effects have been highly educated; for example, patient DM studied by Breedin et al. (1994) was a professional with a master's degree and patient AB examined by Warrington (1975) was a high-ranking civil servant. These individuals might have had greater familiarity with less frequent abstract words, protecting these concepts to some degree from the effects of semantic degradation. Against this hypothesis, there was no clear relationship between educational level and the size of the imageability effect in the current study. We have demonstrated that high levels of education are not *always* accompanied by reverse concreteness effects (one of the patients showing the standard pattern here had obtained a PhD). Nevertheless, the number of years spent in education is at best a crude measure of individual differences in premorbid exposure to abstract and concrete vocabulary. In addition, continued use of abstract and concrete words later in life might be a more critical factor. Very little is currently known about the fate of general vs. specialised, expert knowledge in SD – therefore an interesting question for further research is the extent to individual differences in education or ongoing experiences affect the profile of semantic degradation across different categories of knowledge.

The main contribution of the current study is to show that these individual cases with reverse imageability effects are not representative of SD more generally. Instead, every patient in our case-series study showed poorer comprehension of abstract than concrete words, suggesting that the ATL semantic system underpins the meanings of both imageable and abstract concepts.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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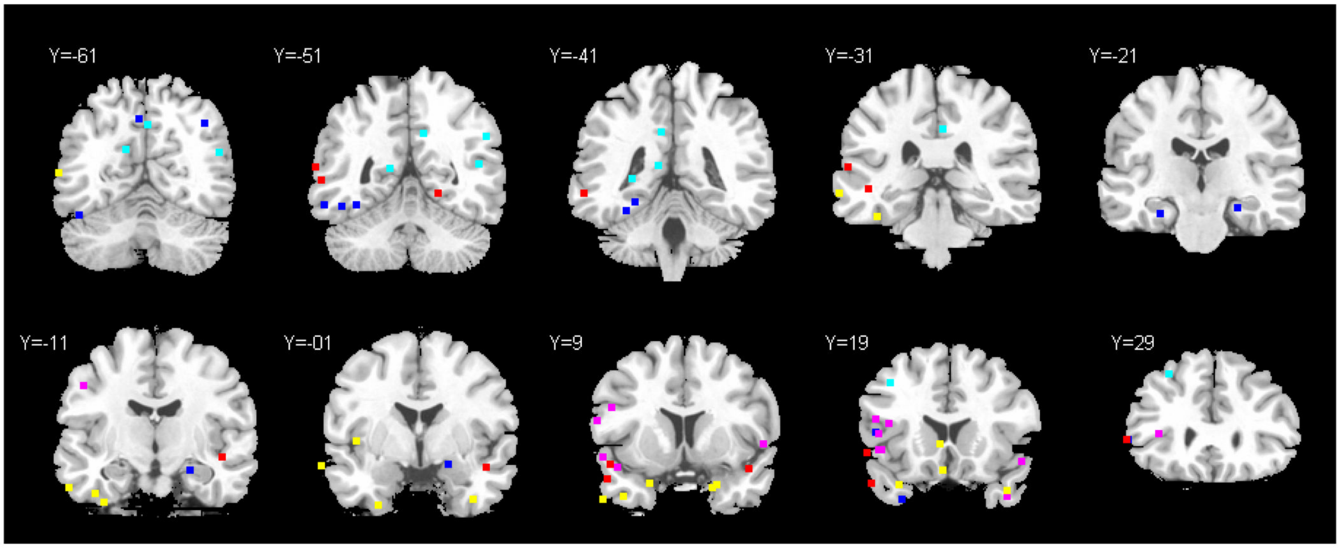

Figure 1. Meta-analysis of functional neuroimaging studies directly comparing concrete and abstract words

Note: Twelve functional neuroimaging studies supplied the peaks (Binder et al., 2005; Fiebach & Friederici, 2003; Giesbrecht et al., 2004; Grossman et al., 2002; Jessen et al., 2000; Kiehl et al., 1999; Noppeney & Price, 2002; ^{2004}; Perani et al., 1999; Sabsevitz et al., 2005; Whatmough et al., 2004; Wise et al., 2000). Red/Pink = sites showing greater activation for abstract stimuli (pink = lexical decision; red = other tasks, primarily semantic judgements). Blue/cyan = sites showing greater activation for concrete stimuli (cyan = lexical decision; blue = other tasks, primarily semantic judgements). Yellow = sites of peak atrophy (Mummery et al., 2000) and hypometabolism (Nestor et al., 2006) in SD.

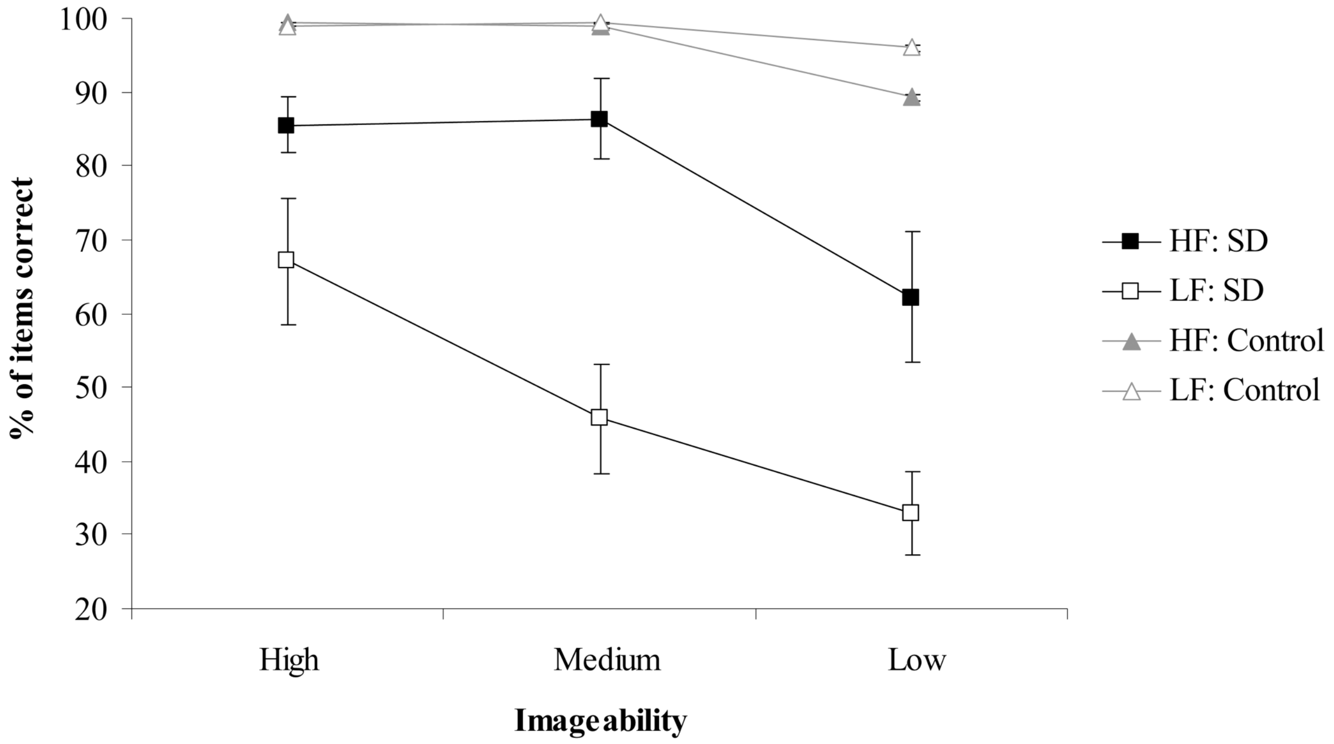

Figure 2. Performance on the synonym judgement task
Error bars show standard error of mean

Table 1

Biographical details and background neuropsychological scores

	AN	LS	SJ	WM	EK	ATe	GE	KI	GT	PD	MK	No. items
Age	64	60	59	54	59	66	50	65	70	72	67	
Sex	M	M	F	F	F	M	M	M	M	F	F	
Education (leaving age)	14	18	16	21	15	24	16	14	14	14	17	
Composite semantic score	1.7	1.2	0.8	0.6	0	−0.2	−0.4	−0.5	−0.5	−1.4	−1.4	
Word-picture match	63	63	59	52	46	58	32	36	32	17	11	64
Picture naming	53	43	29	26	17	10	13	15	11	4	2	64
PPT: Pictures	NT	49	48	44	35	47	34	31	37	26	33	52
PPT: Words	NT	49	42	39	36	44	28	35	32	26	26	52
CCT: Pictures	49	53	51	52	33	40	32	20	27	17	26	64
CCT: Words	55	54	47	30	26	45	27	33	28	24	NT	64
Fluency: 8 categories	60	32	31	30	31	6	22	27	24	7	1	-
Fluency: 3 letters	32	7	23	NT	29	8	19	17	24	22	2	-
Raven's Matrices	35	31	34	35	33	32	33	21	35	25	22	36
Digit span forwards	8	8	5	8	6	7	7	8	6	7	5	-
Digit span backward	6	7	3	5	7	4	4	5	4	5	4	-
Rey Figure copy	36	21	33	36	34	36	35	34	34	36	30	36
VOSP: Screening	NT	16	20	NT	20	19	20	20	20	19	17	20
VOSP: Dot counting	NT	10	10	NT	10	10	10	10	10	10	10	10
VOSP: Position discrimin	20	20	20	NT	20	20	20	19	20	16	17	20
VOSP: Number location	10	10	10	NT	10	8	9	10	10	9	6	10

Patients are arranged in order of composite semantic score, derived from word-picture matching, picture naming, picture CCT and category fluency. PPT = Pyramids and Palm Trees test (Howard & Patterson, 1992). CCT = Camel and Cactus Test, a test of semantic associations for words and pictures, similar to the PPT test but with four choices per trial (Bozeat et al., 2000). Fluency = total number of words produced in one minute, from eight semantic categories and three letters combined. Raven’s Matrices = Coloured Progressive Matrices Test, tapping non-verbal reasoning (Raven, 1962). Digit span from Wechsler Memory Scale (Wechsler, 1987). Rey Figure copy involved copying a complex geometrical figure. VOSP = Visual Object and Space Perception battery (Warrington & James, 1991).

Table 2

Synonym judgement results for individual SD patients

	AN	LS	SJ	WM	EK	ATe	GE	KI	GT	PD	MK
HI, HF	93.8	62.5	100	100	93.8	75.0	93.8	90.6	81.3	75.0	75.0
HI, LF	100	87.5	100	93.8	87.5	18.8	43.8	56.3	62.5	56.3	31.3
MI, HF	100	93.8	100	100	100	50.0	100	75.0	87.5	87.5	56.3
MI, LF	56.3	62.5	87.5	62.5	43.8	12.5	37.5	34.4	43.8	62.5	0
LI, HF	93.8	68.8	81.3	93.8	62.5	6.3	93.8	65.6	43.8	56.3	18.8
LI, LF	62.5	25.0	43.8	56.3	37.5	0	25.0	37.5	37.5	31.3	6.3
HF average	95.8	75.0	93.8	97.9	85.4	43.8	95.8	77.1	70.8	72.9	50.0
LF average	72.9	58.3	77.1	70.8	56.3	10.4	35.4	42.7	47.9	50.0	12.5
HI average	96.9	75.0	100	96.9	90.6	46.9	68.8	73.4	71.9	65.6	53.1
MI average	78.1	78.1	93.8	81.3	71.9	31.3	68.8	54.7	65.6	75.0	28.1
LI average	78.1	46.9	62.5	75.0	50.0	3.1	59.4	51.6	40.6	43.8	12.5
Total correct	84.4	66.7	85.4	84.4	70.8	27.1	65.6	59.9	59.4	61.5	31.3

Table shows percentage of items that were correct in each condition. Patients are arranged in order of composite semantic score. HI = high imageability; MI = medium imageability; LI = low imageability; HF = high frequency; LF = low frequency.