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Be concrete to be comprehended: Consistent imageability effects in semantic dementia for nouns, verbs, synonyms and associates

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Running header: Imageability in semantic dementia

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Abstract

There are two contrasting views on the nature of comprehension impairment in semantic dementia: (a) that it stems from degradation of a pan-modal "hub" that represents core conceptual knowledge or (b) that it results from degradation of modality-specific visual feature knowledge. These theories make divergent predictions regarding comprehension of concrete vs. abstract words in the disorder. The visual hypothesis predicts that concrete words should be particularly impaired because they depend heavily on visual information. In contrast, the pan-modal hub hypothesis holds that all types of knowledge are affected but predicts *less* severe impairment of concrete words because they have richer and more detailed semantic representations than abstract words. We investigated concreteness effects in the comprehension of six SD patients. Across nouns, verbs, synonymous and associative relationships, a clear and consistent pattern emerged: concrete words were always comprehended more successfully than abstract words. These findings extend those of previous studies and suggest that conceptual impairment in SD is not confined to concepts that rely on visual information. Instead, all types of knowledge are affected by the progressive deterioration of modality-invariant representations (required for coherent pan-modal concepts). Concrete words succumb less quickly by virtue of their richer and more detailed semantic representations.

Keywords: concreteness; semantic cognition; conceptual knowledge; progressive aphasia

1. Introduction

This study is concerned with the nature of the semantic impairment in semantic dementia (SD), a neurodegenerative condition in which atrophy centred on the inferolateral, anterior temporal lobe accompanies a progressive and eventually profound breakdown in semantic knowledge (Hodges and Patterson, 2007; Snowden et al., 1989). Because SD patients present with a central and highly selective semantic deficit, the disorder is an important source of evidence for theories of semantic knowledge (Jefferies and Lambon Ralph, 2006; Patterson et al., 2007; Rogers et al., 2004; Simmons and Martin, 2009). A key issue in interpreting the nature of the disorder is to determine whether any particular domains of knowledge are disproportionately impaired. Though SD patients have an indisputable deficit in understanding concrete concepts (e.g., manmade objects and living things; Bozeat et al., 2000; Bozeat et al., 2002; Garrard and Carroll, 2006; Luzzi et al., 2007), the status of abstract word knowledge (e.g., *advantage* or *chance*) is more contentious. Comprehension deficits following brain damage typically affect abstract words to a greater extent than concrete words (Coltheart, 1980; Franklin, 1989; Hoffman et al., 2010; Hoffman et al., 2011; Katz and Goodglass, 1990), in line with more efficient processing of concrete words in healthy subjects (Degroot, 1989; James, 1975; Kroll and Merves, 1986). However, there are a number of reports of SD patients who show a *reversal* of this standard effect, i.e. better comprehension of abstract relative to concrete words (Breedin et al., 1994; Cipolotti and Warrington, 1995; Macoir, 2009; Papagno et al., 2009; Reilly et al., 2007; Warrington, 1975). Throughout the paper, we refer to this as an A>C pattern of comprehension.

These unusual "reversals" of the typical concreteness effect have been interpreted in two ways. Some researchers take them to be an important signature of the underlying semantic impairment in SD. On this view, SD patients suffer from damage to the visual association cortex in the ventral temporal lobes, which is particularly important for the representation of concrete words (Bonner et al., 2009; Breedin et al., 1994; Macoir, 2009; Yi et al., 2007). Because the meanings of abstract words depend strongly on verbal associations and are less dependent on visual perceptual information (Paivio, 1986), their semantic representations are thought to be relatively spared. The semantic representations of abstract words might depend more heavily on superior temporal regions specialised for verbal comprehension, which are less severely affected in SD (Galton et al., 2001).

Other researchers maintain that A>C effects are not informative about the nature of semantic impairment in SD because they only occur in a small subset of SD cases (Hoffman and Lambon Ralph, 2011; Jefferies et al., 2009). Most reports of A>C effects are from single-case studies and until recently there had been no attempt to determine whether these cases were representative of the typical pattern of impairment in the disorder. The inferolateral aspects of the anterior temporal lobes are the focus of atrophy and hypometabolism in SD patients (Galton et al., 2001; Nestor et al., 2006). However, repetitive transcranial magnetic stimulation to this region in healthy subjects produces a greater (temporary) impairment for abstract over concrete words (i.e., a C>A pattern; Pobric et al., 2009). This runs counter to the idea that anterior temporal lobe atrophy gives rise to an A>C pattern of comprehension. Instead, these findings predict that SD patients should typically exhibit C>A effects, a view that is more in keeping with the "hub-and-spoke" semantic framework (Patterson et al., 2007; Pobric et al., 2010; Rogers et al., 2004). This theory states that semantic representations are underpinned by (a) a network of modality-specific regions of cortex distributed throughout the brain ("spokes") and (b) a pan-modal "hub" that merges input from these regions to form modality-invariant, coherent conceptual representations (Lambon Ralph et al., 2010). Semantic impairment in SD is thought to arise from damage to the hub, affecting all types of semantic knowledge irrespective of whether they depend on visual or verbal information. On this view, abstract words are disproportionately impaired simply because they have intrinsically weaker semantic representations. Their weaker representation comes about because they are not associated with the rich perceptual experiences that characterise concrete words (Jones, 1985; Paivio, 1986; Plaut and Shallice, 1993). On this view, occasional reports of individual patients showing A>C effects represent a deviation from the typical pattern of semantic breakdown in SD.

A number of recent studies have attempted to adjudicate on this issue by assessing concrete and abstract knowledge in larger groups of SD patients. In support of the visual deficit hypothesis, Yi et al. (2007) tested 12 SD patients with a description-to-word matching task and found an A>C pattern for verbs, with nine patients showing an effect in this direction. However, there was no such effect for comprehension of nouns. In a follow-up study, Bonner et al. (2009) tested eleven patients with a synonym matching task with verbs and found a similar pattern at the group level. In contrast, Jefferies et al. (2009) gave a synonym judgement task consisting mostly of nouns to eleven SD patients and found a strong C>A effect, which was present at a statistically significant level in all eleven individuals. The differences between these studies could have arisen from differences in the patients themselves or variation in the experimental stimuli used to assess knowledge. We recently tested a single set of seven SD patients on all of the tasks from the above studies, along with some other concrete-abstract assessments (Hoffman and Lambon Ralph, 2011). Averaged across all tasks, there was a significant C>A effect, supporting the hub-and-spoke interpretation. There were also some informative differences between tasks. The Jefferies et al. task yielded a robust C>A effect, while no difference between concrete and abstract words emerged for the Yi et al. and Bonner et al. verb tasks. We attributed this variability to differences in the stimuli used in the various tasks. Tasks were more likely to reveal a C>A effect if they: (a) ensured that concrete and abstract words employed in the task were fully separated along the imageability scale and (b) ensured that stimuli were matched across conditions for word frequency. The two verb tasks did not meet these criteria. The selected concrete and abstract words were quite similar in imageability, resulting in lower sensitivity to concreteness effects than the Jefferies et al. task. Moreover, the abstract conditions featured higher frequency words than the concrete conditions. Lexical frequency has a powerful influence in SD, with patients invariably showing better comprehension of higher frequency/more familiar words (Funnell, 1995; Hoffman et al., 2011; Jefferies et al., 2009; Lambon Ralph et al., 1998). Consequently, these two methodological factors may have conspired to produce an apparent A>C effect for the Yi et al. and Bonner et al. stimuli.

We proposed that these differences in frequency and imageability (summarised in Table 1) can account for the inconsistent results across studies. However, another possibility is that the word class of the stimuli is a critical factor in determining the type of concreteness effects observed. Jefferies et al. (2009) employed mostly nouns in their test, while Bonner et al. (2009) used only verbs. In addition, Yi et al. (2007) found an A>C effect for verbs but no effect for nouns. Yi et al. claimed that concrete nouns are partially protected from semantic degradation because they belong to dense semantic neighbourhoods. Because concrete nouns tend to have many semantic neighbours with similar features, when a particular concept degrades it can be partially supported by remaining knowledge for its neighbours (Gonnerman et al., 1997). The same was not thought to be true of concrete verbs, which have fewer neighbours. Thus, while visual feature degradation predicts greater impairment for concrete words, this effect tends not be observed with nouns because concrete nouns are protected by virtue of their dense neighbourhoods. This is a critical point because it calls into question into the C>A effects reported by Jefferies et al. (2009) and Hoffman and Lambon Ralph (2011). These authors reported robust C>A effects in SD patients, but used nouns predominantly as stimuli. The visual feature hypothesis predicts that an A>C effect would emerge if the same patients were tested with verb stimuli.

In the present study, we directly compared concreteness effects for nouns and verbs in six SD patients, including five individuals who showed C>A effects for nouns in our previous study (Hoffman and Lambon Ralph, 2011). We paid particular attention to the key stimulus factors described above. We maximised the difference in imageability values between concrete and abstract words and we ensured that all of the words in each condition were carefully matched for lexical frequency. This allowed us to test whether A>C effects were present for verbs, as predicted by the visual deficit hypothesis, once the relevant stimulus factors were controlled for.

-Table 1 around here-

In a second experiment, we investigated another factor thought to influence concreteness effects. The Jefferies et al. test, in common with many other comprehension assessments, probed knowledge of synonymous relationships between words (e.g., *frog* and *toad*). This type of semantic relationship may not be well-suited to probing abstract word knowledge. While the semantic representations of concrete words are thought to be organised according to similarity in features, associative relationships (e.g., *religion* and *prayer*) are more important for abstract words (Crutch et al., 2009; Crutch and Warrington, 2005). Thus C>A effects may arise in synonym judgement tests because the format of the test is more compatible with the organisation of concrete concepts. The predicts that an A>C pattern could be observed in SD patients if their knowledge of associative relationships was probed. To test this prediction, we compared concrete and abstract words in an associative matching test. If the C>A effects in previous studies were due to the use of synonym judgements, one would expect a different pattern to emerge with this paradigm. We also included a second concrete condition in which probe and target shared perceptual similarity, to compare directly associative and similarity-based judgements for concrete words.

2. Experiment 1: Concreteness Effects for Nouns and Verbs

2.1. Patients: Six patients with a clinical diagnosis of SD took part in this and the subsequent experiment. They fulfilled all of the clinical criteria for SD (Hodges et al., 1992): they had word-finding and comprehension difficulties in the context of fluent and grammatically correct speech and they also showed non-verbal semantic deficits. Visuospatial skills, executive function and day-to-day memory were relatively preserved. Structural imaging (MRI or CT) revealed bilateral ATL atrophy in all cases. Five of the patients took part in a previous study on concreteness effects (Hoffman and Lambon Ralph, 2011), in which we demonstrated that they showed a C>A pattern in a synonym judgement task composed primarily of nouns. In the present study, we investigated their performance with words of different classes (Experiment 1) and with associative semantic relationships (Experiment 2).

Patients completed a range of background neuropsychological tests, summarised in Table 2. To assess general cognitive function, the Addenbrooke's Cognitive Examination – Revised (ACE-R; Mioshi et al., 2006) was administered. This revealed impairment in all patients on the language and memory sections; in contrast, visuospatial and orientation elements were relatively preserved. Attentional and executive skills were assessed with forward and backward digit span (Wechsler, 1987) and Raven's coloured progressive matrices (Raven, 1962). Two subtests from the Visual Object and Space Perception battery (Warrington and James, 1991) were given to assess visuospatial skills, along with direct copying of the Rey complex figure (Rey, 1941). Scores were within the normal range on all of these tests.

-Table 2 around here-

We assessed semantic knowledge with the Cambridge Semantic Battery (Bozeat et al., 2000), which probes knowledge of the same 64 concrete items (animals, birds, fruit, household objects, tools and vehicles) across different input and output modalities. The following tests were administered: (a) picture naming, in which the 64 items were presented as black-and-white line drawings; (b) spoken word-picture matching, where the correct item must be selected from a field of 10 objects from the same category; (c) the picture Camel and Cactus test, a non-verbal associative matching task in which a concept is presented and the most semantically-related item is selected from four alternatives (e.g., which goes with *camel*: *rose*, *tree*, *sunflower* or *cactus*?); (d) category fluency, in which the patient produces as many items from a given category as possible in one minute. These tests revealed multimodal semantic impairments in all patients, with all scores falling outside the normal range on all tests.

2.2. Control Participants: Ten healthy individuals from the Neuroscience and Aphasia Research Unit (NARU) volunteer panel (University of Manchester) served as controls. Their mean age was 67.9 and they had a mean educational level of 16.4 (school-leaving age). These values did not differ from the patient group ($t(14) < 1$). None had any history of neurological illness and all scored at least 90/100 on the ACE-R.

2.3. Task: Patients performed a synonym matching task. Each trial consisted of a probe word presented with three choices, one of which had a similar meaning to the probe. The remaining two choices were not semantically related (e.g., *frog* was presented with *toad*, *jewel* and *pickle*). The probe and three choices were presented in a written format and were also read aloud by the examiner.

2.4. Stimuli: There were 120 trials in total, 60 nouns and 60 verbs, with half of the trials in each condition probing concrete words and half abstract words (see Appendix 1 for a full list). Imageability ratings from two published databases were used to guide stimulus selection (see below). There is a technical distinction between imageability, the degree to which a word elicits a mental image, and concreteness, the degree to which it refers to a tangible item. Despite being distinct psycholinguistic variables, they are very strongly correlated (typically with $r > 0.8$). Importantly, the visual deficit hypothesis predicts that concrete words are more impaired than abstract because they are more imageable and depend on visual feature information to a greater extent. For this reason, and in common with other studies of concreteness effects in SD (Bonner et al., 2009; Jefferies et al., 2009; Macoir, 2009), we used imageability ratings to distinguish between concrete and abstract words.

Psycholinguistic properties for each set of words are given in Table 3. The frequency and imageability values of probe and choice words were matched across conditions. Lemma frequency values were obtained from the CELEX database (Baayen et al., 1993). The frequencies of probes and choice words were subjected to 2 × 2 (word class × imageability) ANOVAs, which indicated no difference between nouns and verbs or between concrete and abstract words for either probe or choice words ($F < 0.5$ in all cases). Imageability values were taken from Bird et al.'s (2001) ratings, which contain separate values for the noun and verb senses of ambiguous words (e.g., "a whistle" is rated separately from "to whistle"). We also used ratings from the MRC database (Coltheart, 1981) for words that could be classed unambiguously as either nouns or verbs. ANOVAs indicated that concrete words were more imageable than abstract ($F > 2663$) but that there was no difference between nouns and verbs ($F < 0.5$). There were also no interactions between word class and imageability ($F < 2.27$, $p > 0.1$), indicating that, unlike previous studies, the imageability manipulation for verbs was equal in strength to that for nouns. Given the close matching for frequency it was not possible to match all conditions for word length. There was no a priori reason to expect word length to influence comprehension in SD; but to ensure that this factor could not account for our results, in addition to analysing results across participants, we performed a by-items ANCOVA that included length as a covariate.

-Table 3 around here-

<u>2.5. Results:</u> Results for each patient are shown in Figure 1. To analyse data at the group level, we conducted a 2 × 2 × 2 ANOVA that included group as a between-subjects factor and word class and imageability as within-subjects factors. There were main effects of group ($F(1,14) = 23.4$, $p < 0.001$) and imageability ($F(1,14) = 30.4$, $p < 0.001$) but no effect of word class. Additionally, there was a group × imageability interaction ($F(1,14) = 24.9$, $p < 0.001$), indicating that patients showed larger imageability effects than controls. There was no interaction between word class and imageability, but the three-way interaction approached significance ($F(1,14) = 3.60$, $p = 0.079$). Imageability effects were also analysed for nouns and verbs separately within the SD group, with a significant C>A effect emerging for both word classes (nouns: $t(5) = 4.17$, $p < 0.001$; verbs: $t(5) = 3.69$, $p < 0.02$). There was no imageability × word class interaction within the SD group ($F(1,5) = 2.36$, $p > 0.1$).

Finally, to ensure that the observed imageability effects were not due to differences in word length across conditions, we used ANCOVA to analyse the data, treating each word as a separate case and including word length as a covariate of no interest. Significant effects of group ($F(1,115) = 22.6$, $p < 0.001$) and imageability emerged ($F(1,115) = 53.5$, $p < 0.001$), as well as the expected group × imageability interaction ($F(1,115) = 55.0$, $p < 0.001$). There were no effects of word class nor any other interactions.

-Figure 1 around here-

<u>2.6. Discussion:</u> SD patients showed equivalent C>A effects in comprehension of verbs and nouns. This is in line with the hub-and-spoke model of semantic representation, which states that damage in SD affects a store of modality-invariant conceptual knowledge, which is key to the coherence of all concepts. On this view, concrete words are affected to a lesser extent

because they are associated with richer sensory experiences, leading to a more robust representation (Plaut and Shallice, 1993). These findings are not compatible with the idea that the primary deficit in SD is degradation of visual feature knowledge, as this deficit would affect concrete words to a greater extent than abstract words. Proponents of this view propose that such A>C effects are more likely to be observed for verbs because impaired comprehension for concrete nouns is partially ameliorated by their dense semantic neighbourhoods (Yi et al., 2007). However, when controlling for the relevant psycholinguistic factors, we observed equivalent C>A effects for nouns and verbs. A>C effects observed for verbs in previous studies are most likely a consequence of weaker imageability manipulations in these studies combined with differences in word frequency between concrete and abstract words (Hoffman and Lambon Ralph, 2011).

3. Experiment 2: Concreteness Effects for Associative Relationships

3.1. Patients: The six SD patients from Experiment 1 took part in this experiment.

3.2. Control Participants: Ten healthy individuals from the Neuroscience and Aphasia Research Unit (NARU) volunteer panel acted as controls. They had a mean age of 69.8 and mean educational level of 17.0 (school-leaving age). These values did not differ from the patient group ($t(14) < 2$, $p > 0.07$). None had any history of neurological illness and all scored at least 90/100 on the ACE-R.

3.3. Task: On each trial, participants were presented with a probe word and three choices and were asked to pick the word most related in meaning to the probe. The two foils were not semantically related to the probe. The probe and three choices were presented in a written format and were also read aloud by the examiner.

3.4. Stimuli: There were three conditions. 40 trials featured abstract words that shared an associative relationship (e.g., *mercy* and *plead*). 40 trials featured concrete words that were associated but were not perceptually similar (e.g., *hamster* and *cage*). The final condition used the same concrete probes but this time paired with semantically related words that shared some perceptual similarity (e.g., *hamster* and *mouse*). We included this condition to assess knowledge of associative vs. similarity-based judgements within concrete words. Strength of association between probes and targets was controlled using free association norms from the Edinburgh Word Association Thesaurus (Kiss et al., 1973). Each probe-target pairing in the experiment was present in the norms, with associative strengths of between 2% and 25% (i.e., each target word was produced in response to its probe by between 2% and 25% of subjects). The associative strength of probe-target pairs was matched across all three conditions (see Table 4; $F < 1$). In addition, the frequencies of probes and choice words were matched across conditions (probes: $t < 1$; choices: $F < 0.2$). Imageability ratings were obtained from the MRC database (Coltheart, 1981) and the Bristol norms (Stadthagen-Gonzalez and Davis, 2006). Imageability values differed significantly between abstract and concrete conditions (probes: $t = 36.3$, $p < 0.001$; choices: $t > 42$, $p < 0.001$). However, imageability was matched across the two concrete conditions ($t < 1$). It was again not possible to match all conditions for word length so an additional by-items analysis was conducted, including length as a covariate.

-Table 4 around here-

3.5. Results: Accuracy in each condition is presented in Figure 2. Data were analysed with a 3 × 2 ANOVA that included condition and group as factors. There were main effects of group

($F(1,14) = 24.5$, $p < 0.001$) and condition ($F(2,28) = 61.4$, $p < 0.001$) and a significant interaction ($F(2,28) = 34.0$, $p < 0.001$). Post-hoc tests conducted on the patient data with a Bonferoni-corrected significance level of 0.016 indicated that all three conditions differed from one another. Comprehension in the abstract condition was poorer than either of the concrete conditions (abstract vs. concrete associate: $t(5) = 4.53$, $p < 0.01$; abstract vs. concrete perceptual: $t(5) = 7.20$, $p = 0.001$) and, furthermore, comprehension of concrete words was significantly better when they shared a perceptual relationship ($t(5) = 3.78$, $p = 0.013$). Finally, ANCOVA including word length as a covariate also revealed effects of group ($F(1,116) = 9.58$, $p < 0.005$) and condition ($F(2,116) = 14.1$, $p < 0.001$), plus the expected interaction ($F(2,116) = 10.3$, $p < 0.001$).

-Figure 2 around here-

<u>3.6. Discussion:</u> SD patients continued to show a robust C>A effect when knowledge was probed using associative rather than similarity-based relationships. This indicates that the C>A effect does not depend critically on the type of relationship used to interrogate semantic knowledge. Associative relationships might be expected to facilitate comprehension of abstract words, yet when associative judgements for concrete and abstract words were directly compared, performance was still better for concrete words. However, the C>A effect was smaller than those observed in the previous (synonym-based) experiment, suggesting that the type of semantic relationship may influence the size of concreteness effects. We also found that, within concrete words, similarity-based relationships were better comprehended than associative ones. This is consistent with the idea that the semantic space for concrete words is organised in terms of their similarity (Crutch and Warrington, 2005) and suggests that the patients benefited from the shared perceptual information that was available when the target and probe were similar and not merely associated.

4. General Discussion

The status of concrete vs. abstract word knowledge in SD has proved a contentious issue, with some arguing that concrete words are disproportionately affected by the disorder, suggesting underlying damage to visual-perceptual feature information (Bonner et al., 2009; Breedin et al., 1994; Yi et al., 2007). Conversely, previous studies from our own group have shown that the typical pattern in SD is for concrete words to be more preserved than abstract words, provided that the test is sufficiently sensitive to detect such effects (Hoffman and Lambon Ralph, 2011; Jefferies et al., 2009). Here, we extended these findings by establishing that the C>A effects present in SD patients are consistent across a range of materials, for which other theories specifically predict A>C effects. In contrast to these other predictions, we found the typical C>A pattern held for verbs as well as nouns, and for associates as well as synonyms. These findings are inconsistent with the idea that visual feature knowledge, thought to be more important for concrete words, is disproportionately impaired in the disorder. They are more compatible with the view that SD patients suffer from degradation of modality-invariant semantic representations that are equally important for concrete and abstract words. On this view, inferior, anterior temporal cortex – the focus of atrophy in SD – is the centre of a semantic "hub" that uses inputs from a number of modality-specific processing regions to distil information into coherent concepts (Lambon Ralph et al., 2010; Patterson et al., 2007; Rogers et al., 2004).

If the hub is thought to represent core conceptual knowledge for all types of concept, how does the hub-and-spoke theory account for the clear finding that abstract words are more severely affected in SD than concrete words? It is widely accepted that abstract words have intrinsically weaker semantic representations because they are not associated with the rich perceptual experiences that are typical of concrete words (Plaut and Shallice, 1993). Healthy subjects, for example, produce fewer predicates for abstract words (Jones, 1985) and generate fewer and less specific semantic properties when asked to define abstract compared with concrete words (Wiemer-Hastings and Xu, 2005). As conceptual knowledge progressively degrades in SD, abstract words will tend to drop below the “threshold” for successful comprehension more quickly than concrete words because their representations are weaker to begin with. Less efficient processing of abstract words is evident in healthy subjects’ reaction times on tasks such as lexical decision (Degroot, 1989; James, 1975; Kroll and Merves, 1986). On this view, C>A effects in SD reflect an exaggeration of this intrinsic pattern.

This study, along with previous investigations (Hoffman and Lambon Ralph, 2011; Jefferies et al., 2009), suggests that the unusual A>C effects sometimes reported in SD patients are *not* typical of the disorder. Most studies reporting such effects have focused on robust A>C effects in *individual* SD cases (Breedin et al., 1994; Cipolotti and Warrington, 1995; Macoir, 2009; Papagno et al., 2009; Warrington, 1975). While these rare cases are striking and require explanation, they are not representative of the most common pattern of comprehension impairment in SD. Small A>C effects have also been reported in *groups* of SD patients in comprehension of verbs (Bonner et al., 2009; Yi et al., 2007). In our view, these apparent A>C effects are in fact due to characteristics of the experimental materials. These studies used a relatively weak concreteness manipulation which, when combined with a tendency for abstract verbs to be higher in frequency than concrete verbs, led to better comprehension in the abstract condition (Hoffman and Lambon Ralph, 2011).

Our view is that patients who show A>C effects deviate from the typical presentation of SD in some critical way. In the absence of any direct comparisons between patients who show divergent concreteness effects, it is difficult to ascertain the precise nature of this difference. However, we have suggested previously that neuroanatomical or demographic factors may be responsible. Temporal lobe atrophy in SD is usually centred on the anterior inferolateral surface (Galton et al., 2001; Mummery et al., 2000) but there is individual variation in the extent and precise distribution of damage. There are two temporal lobe sites beyond the anterior “hub” region, for which atrophy might be expected to cause an A>C effect. First, the superior temporal sulcus is strongly associated with verbal comprehension (Hickok and Poeppel, 2007; Scott et al., 2000; Sharp et al., 2004) and is often activated in neuroimaging studies for abstract words (Binder et al., 2009; Sabsevitz et al., 2005), in line with the idea that abstract words depend heavily on verbal associative knowledge. If this region were relatively spared in a particular patient (i.e., their pathology was focused especially on the anterior basal temporal area), comprehension of abstract words might be relatively preserved. Alternatively, the posterior ventral temporal lobe is associated with visual feature knowledge (Chao et al., 1999; Martin, 2007) and is strongly activated by concrete words (Sabsevitz et al., 2005; Wise et al., 2000). Atrophy in this region, posterior to the typical focus of damage in SD, is likely to affect concrete words to a greater extent than abstract words, again giving rise to an atypical A>C pattern in comprehension.

One final possibility is that variation in educational and occupational experience could affect how concrete and abstract words are affected by the disease. Most reported A>C patients were professionals (e.g., a professor of psychology; Macoir, 2009) whom one would expect to be highly literate and perhaps more familiar with abstract terms than most members of the population. This might afford abstract words a degree of protection in these individuals, since loss of semantic knowledge is strongly graded by word frequency/familiarity. In this study and most others, care has been taken to match concrete and abstract words for lexical frequency. However, this does not preclude the possibility that particular patients have had atypical premorbid experiences in which they used abstract terms very often. Indeed, a recent study has demonstrated that this kind of premorbid expertise does lead to more robust semantic representations as a result of the increased quality and quantity of each patient’s individual experience (Jefferies et al., 2011).

It is not yet clear which factors cause occasional, individual patients to display preserved abstract word knowledge. What is clear from a number of tasks and materials is that SD patients *typically* lose comprehension of abstract words more quickly than that of concrete words. This, we argue, is due to degradation of core conceptual knowledge, which affects abstract words to a greater extent because their semantic representations are weaker and less detailed than those of concrete words. When semantic knowledge is under threat from anterior temporal atrophy, the rule, it seems, is to be concrete to be comprehended.

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Table 1: Summary of previous imageability studies in groups of SD patients

Study	Word class of stimuli	Concreteness manipulation	Frequency matching	Observed effect
Jefferies et al. (2009)	Mostly nouns	Large difference in imageability between concrete and abstract words	Probes and choices matched for frequency	C>A
Yi et al. (2007)	Noun condition	Moderate difference in imageability between concrete and abstract	Targets and foils matched for frequency	C=A
Yi et al. (2007)	Verb condition	Motion vs. cognition verbs; small difference in imageability values	Targets matched for frequency but abstract foils higher in frequency than concrete foils	A>C
Bonner et al. (2009)	All verbs	Small difference in imageability values	Probes matched for frequency but abstract choices higher in frequency than concrete choices	A>C

Description of psycholinguistic properties is based on analysis in Hoffman and Lambon Ralph (2011).

Table 2: Background details and neuropsychological test scores

Test	Max	JW	DF	MT	MB	PL	PW	Control mean (range)
Demographic								
Sex		F	M	F	F	F	M	
Age		63	64	61	61	72	73	
Educational level		16	16	16	15	15	17	
Cambridge Semantic Battery								
Naming	64	43	43	44	32	22	8	62.3 (57-64)
Word-picture matching	64	61	61	50	48	43	33	63.8 (63-64)
CCT pictures	64	49	49	37	30	30	34	59.1 (51-62)
Category fluency (6 categories)	-	53	29	50	37	26	22	95.7 (61-134)
General Neuropsychology								
ACE-R	100	62	65	67	67	56	41	93.7 (85-100)
MMSE	30	29	26	27	27	23	23	
Visuospatial								
Rey figure copy	36	34	34	36	35	31	34	34.0 (31-36)
VOSP number location	10	8	10	10	10	7	10	9.4 (7-10)
VOSP cube analysis	10	10	8	10	10	9	10	9.7 (6-10)
Attention/Executive								
Digit span forward	-	6	6	7	6	8	5	6.8 (4-8)
Digit span backward	-	6	3	6	4	5	4	4.8 (3-7)
Raven's coloured progressive matrices	36	32	31	34	31	31	34	

ACE-R = Addenbrookes Cognitive Examination – Revised (Mioshi et al., 2006); MMSE = Mini-mental state examination (Folstein et al., 1975). VOSP = Visual Object and Space Perception battery (Warrington and James, 1991). CCT = Camel and Cactus test (Bozeat et al., 2000).

Table 3: Properties of stimuli in Experiment 1

Items	Property	Concrete nouns	Abstract nouns	Concrete verbs	Abstract verbs
Probes	Frequency	52 (1-589)	45 (2-338)	48 (1-343)	49 (1-438)
	Imageability	539 (504-587)	282 (242-331)	534 (496-609)	292 (218-331)
	Length	6.9 (3-11)	7.0 (4-11)	5.2 (3-9)	6.3 (3-10)
Choice words	Frequency	42 (1-317)	51 (1-285)	46 (1-399)	47 (1-465)
	Imageability	543 (459-609)	298 (210-386)	535 (433-611)	301 (212-373)
	Length	5.7 (3-10)	8.4 (4-14)	5.0 (3-8)	6.9 (4-11)

Table shows mean values for each condition, with range in parentheses.

Table 4: Properties of stimuli in Experiment 2

Items	Property	Concrete similar	Concrete associates	Abstract associates
Probes	Frequency	41 (2-451)	41 (2-451)	34 (1-258)
	Imageability	598 (551-638)	598 (551-638)	337 (258-397)
	Length	5.6 (3-11)	5.6 (3-11)	6.8 (4-14)
Choice words	Frequency	56 (1-470)	53 (1-359)	58 (1-348)
	Imageability	593 (532-649)	592 (444-649)	368 (262-491)
	Length	5.6 (3-11)	5.4 (3-11)	6.9 (3-13)
Associative strength (%)		7.0 (2.0-25.3)	6.1 (2.1-15.7)	6.6 (2.0-20.4)

Table shows mean values for each condition, with range in parentheses. Probes were identical in concrete associate and concrete similar conditions.

Figure 1: Comprehension of concrete and abstract nouns and verbs

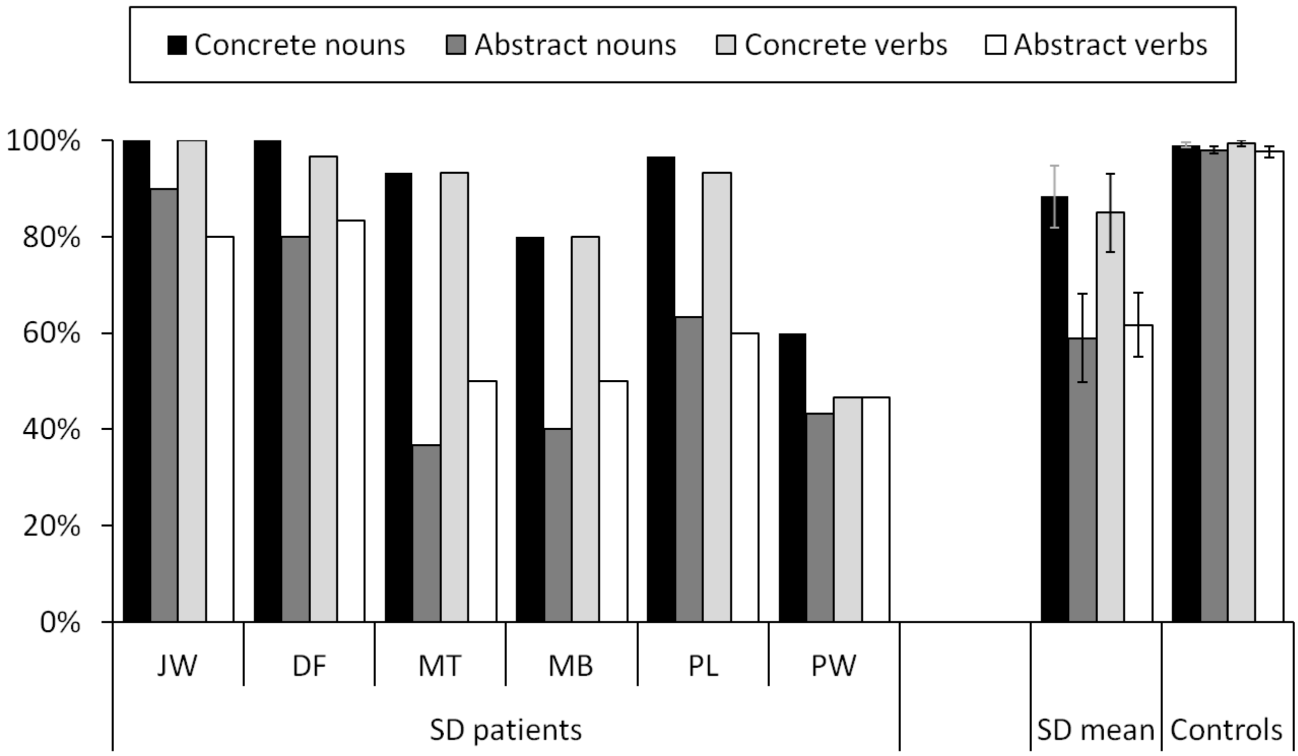
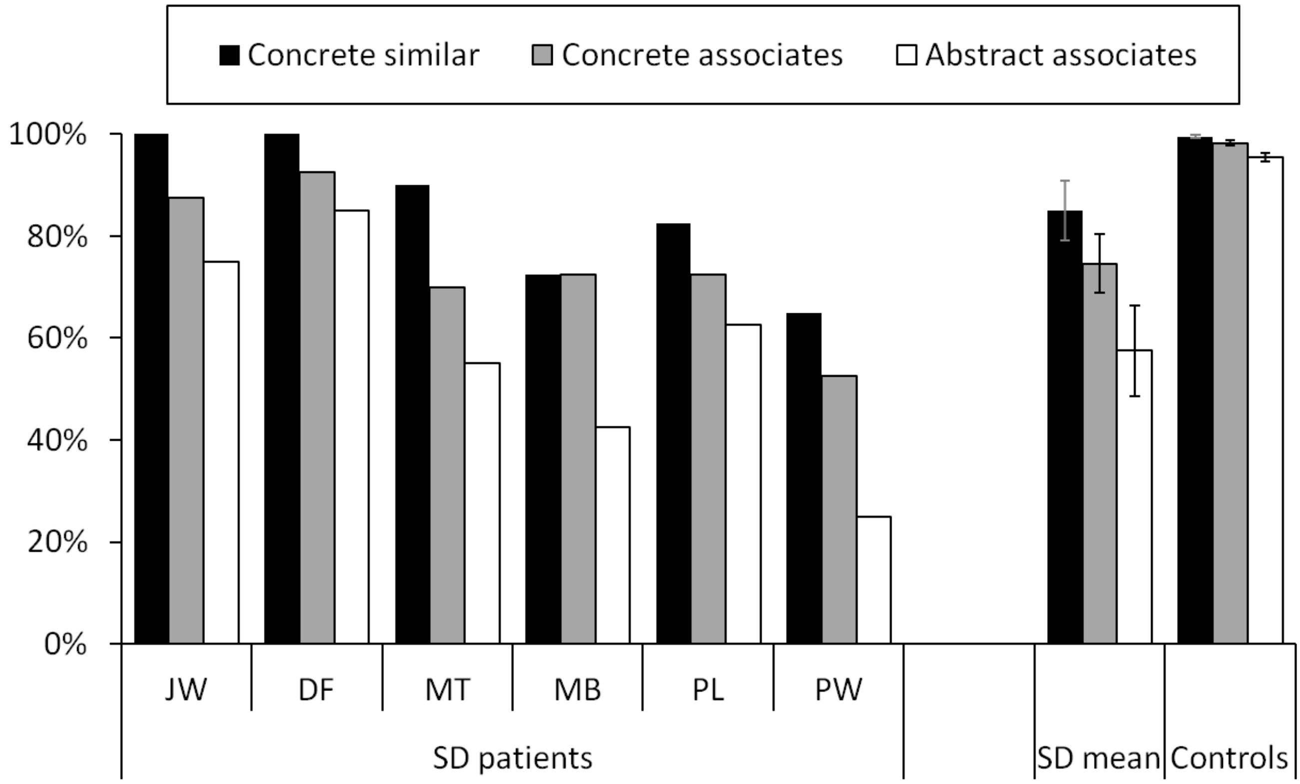


Figure 2: Comprehension of associative relationships for concrete and abstract words



Appendix 1: Stimuli in Experiment 1

Condition	Probe	Target	Foil 1	Foil 2
Abstract nouns	analogy	metaphor	clearance	prohibition
	aptitude	capability	dividend	amendment
	arbiter	mediator	incredulity	edict
	chance	possibility	theory	responsibility
	choice	preference	circumstance	beginning
	concept	notion	arrangement	intention
	diplomacy	tact	creed	disparity
	ease	simplicity	necessity	resolution
	enigma	conundrum	computation	dexterity
	facet	aspect	enterprise	assumption
	gusto	passion	diversity	hypothesis
	hint	clue	frequency	criterion
	implication	suggestion	distinction	tenure
	inquiry	request	impression	context
	instance	example	mind	amount
	meaning	significance	consideration	exception
	mediocrity	normality	supposition	axiom
	momentum	impetus	recollection	complication
	occasion	event	type	method
	origin	source	principle	extent
	outcome	consequence	definition	selection
	protocol	procedure	logic	uncertainty
	ratio	proportion	preparation	essence
	reason	explanation	sort	difference
	reprisal	revenge	pretence	outset
	sect	cult	clarity	proximity
	stupidity	idiocy	rating	query
	tendency	inclination	initiative	grade
	tolerance	patience	irony	realm
	unease	restlessness	magnitude	condemnation
Concrete nouns	academy	institute	trunk	foreigner
	barrister	lawyer	tray	invitation
	cauliflower	broccoli	cavern	bison
	ceiling	roof	lane	passenger
	chart	diagram	belly	comrade
	cheetah	panther	granny	petal
	coach	bus	judge	goal
	cotton	wool	platform	chap
	country	region	morning	age
	dentistry	medicine	widow	dwelling
	disability	handicap	medal	reed

Condition	Probe	Target	Foil 1	Foil 2
	dragon	monster	builder	dummy
	electrician	plumber	ark	tunic
	elf	pixie	icicle	wallaby
	gallery	museum	peasant	lamp
	garment	clothing	corridor	clerk
	hatchet	axe	moisture	oyster
	heat	warmth	hole	pain
	hyena	jackal	chemist	bin
	journal	diary	clay	brass
	journalist	writer	brick	giant
	music	song	yard	danger
	parcel	package	calf	poet
	shelter	refuge	organ	envelope
	slave	servant	van	suit
	street	road	parent	food
	thicket	hedge	ribbon	burial
	trombone	saxophone	toga	nozzle
	villain	crook	herring	aluminium
	waist	torso	goddess	chorus
Abstract verbs	absolve	vindicate	disallow	collate
	assume	expect	stay	cause
	ban	outlaw	relieve	originate
	blame	condemn	determine	transform
	compensate	counteract	impel	debase
	cope	manage	choose	regard
	define	describe	acknowledge	blame
	digress	deviate	defraud	hone
	diminish	decrease	await	resolve
	enforce	implement	allege	deepen
	evolve	improve	prefer	quote
	foretell	predict	lend	disregard
	happen	occur	expect	decide
	infer	deduce	admonish	depose
	instigate	initiate	proffer	implore
	involve	include	develop	consider
	irk	irritate	redeem	foretell
	mislead	deceive	nurture	depict
	motivate	inspire	formulate	foresee
	muse	contemplate	affirm	allot
	permit	condone	regain	damn
	refrain	abstain	covet	specify
	relieve	assist	appreciate	depict

Condition	Probe	Target	Foil 1	Foil 2
	resolve	settle	vary	recommend
	revere	worship	induce	assimilate
	sadden	depress	deliberate	collate
	specify	stipulate	usurp	sadden
	stay	remain	suppose	regard
	subdue	repress	signify	toughen
	tolerate	endure	intrigue	lessen
Concrete verbs	break	smash	enjoy	paint
	breathe	gasp	plant	fry
	carve	chop	curl	assault
	chase	pursue	welcome	murder
	choke	cough	blink	rinse
	comb	brush	bang	harvest
	cuddle	hug	toboggan	hike
	drill	pierce	blush	thump
	embroider	crochet	uncork	pinch
	fall	drop	write	eat
	giggle	chuckle	lecture	cycle
	grill	roast	splash	giggle
	hammer	hit	sweep	boil
	howl	scream	wipe	embrace
	leap	jump	sink	freeze
	mash	crush	adore	ski
	pinch	nip	defrost	jog
	polish	rub	swallow	hunt
	slap	smack	scrub	sketch
	smile	grin	rise	wash
	snooze	doze	shoplift	wrestle
	sob	moan	slam	post
	spill	drip	slice	ascend
	sprint	dash	sunbathe	drum
	thump	punch	chat	wring
	travel	visit	marry	sing
	twist	spin	suck	exercise
	whisk	stir	bomb	bathe
	wreck	demolish	spray	shower
	wrestle	grapple	gargle	mop

Appendix 2: Stimuli in Experiment 2

Condition	Probe	Target	Foil 1	Foil 2
Abstract associates	accent	foreign	slow	recent
	ambition	career	variety	principle
	beware	caution	translation	sentiment
	civil	engineering	introduction	tenure
	clause	paragraph	temptation	reign
	clue	crime	welfare	confidence
	corrupt	vice	remedy	edition
	coward	scared	aloud	extensive
	decree	divorce	virtue	incident
	deity	religion	opposition	insurance
	disgrace	punishment	trend	establishment
	dubious	doubt	value	common
	dumb	blind	permit	discipline
	endure	hardship	prose	jargon
	facility	convenience	hesitation	disgrace
	folly	stupid	rapid	genuine
	gradual	decline	sector	crisis
	helpful	aid	prime	tradition
	impediment	stutter	gist	jeopardy
	indication	hint	equality	despair
	indifferent	apathy	debut	verb
	insight	knowledge	event	production
	knowledge	power	area	moment
	legion	honour	credit	suggestion
	memory	forget	listen	arrive
	mercy	plead	devise	suspend
	oblique	slant	snub	fallacy
	opportunity	luck	excuse	tension
	peer	realm	span	scorn
	prolong	agony	flank	dimension
	protocol	diplomacy	anecdote	impetus
	random	selection	motive	appointment
	reality	dream	population	security
	responsibility	age	interest	result
	rest	peace	statement	duty
	rote	learning	preview	abdication
	scarce	famine	continuation	mimic
	temptation	resist	review	import
	theory	mathematics	permission	republic
	void	null	clemency	buffoon

Condition	Probe	Target	Foil 1	Foil 2
Concrete associates	apple	pie	cigar	sword
	book	library	shirt	cloud
	butcher	cleaver	zipper	fudge
	carrot	rabbit	actress	pillow
	caterpillar	cabbage	throne	nun
	cow	field	doctor	church
	crown	jewel	monk	eagle
	deer	park	paint	king
	desk	pencil	bucket	concert
	diamond	tiara	cranberry	albatross
	ferry	river	hospital	minister
	flute	orchestra	circus	fox
	fog	lamp	uniform	ticket
	garden	rose	supper	flag
	gin	lime	pea	crab
	hamster	cage	pine	knot
	hoof	cow	jacket	prince
	jungle	lion	harvest	mask
	kidney	steak	deer	cane
	lemonade	straw	elephant	doll
	mallet	croquet	mermaid	beehive
	milk	baby	road	city
	moth	flame	piano	chin
	mouse	cheese	crown	heel
	petrol	tank	brush	brick
	pyramid	sand	nurse	breakfast
	rabbit	burrow	puddle	magician
	referee	whistle	statue	blade
	road	car	friend	boy
	shark	teeth	screwdriver	thistle
	slipper	carpet	fence	daisy
	strawberry	tart	toad	scissors
	submarine	fish	tree	hair
	tea	cup	prison	shoe
	tiger	jungle	athlete	crystal
	tooth	dentist	trumpet	pastry
	tractor	engine	bath	sugar
	violin	bow	gallery	camera
	wig	judge	dinner	flower
	wizard	wand	asparagus	casket

Condition	Probe	Target	Foil 1	Foil 2
Concrete similar	apple	orange	cattle	trout
	book	page	phone	king
	butcher	baker	brandy	cage
	carrot	turnip	lantern	yacht
	caterpillar	worm	spoon	toast
	cow	sheep	rock	finger
	crown	coronet	daffodil	projector
	deer	antelope	crater	balloon
	desk	easel	ferret	raspberry
	diamond	ruby	pineapple	chisel
	ferry	ship	painting	circle
	flute	bassoon	corkscrew	scooter
	fog	smog	emerald	sardine
	garden	lawn	harbour	penny
	gin	vodka	buckle	trolley
	hamster	mouse	grandmother	needle
	hoof	foot	street	morning
	jungle	forest	coffee	secretary
	kidney	liver	chess	cement
	lemonade	soda	hawk	vest
	mallet	chisel	mustard	hose
	milk	water	family	book
	moth	mosquito	vase	wallet
	mouse	rat	doll	beard
	petrol	gas	wine	bag
	pyramid	tower	sink	magazine
	rabbit	hare	ink	abbey
	referee	umpire	glacier	sparrow
	road	street	student	body
	shark	whale	galaxy	typewriter
	slipper	boot	grin	sheep
	strawberry	raspberry	kite	clown
	submarine	boat	brain	bread
	tea	coffee	grass	wood
	tiger	lion	weed	organ
	tooth	nail	blanket	butter
	tractor	plough	altar	towel
	violin	cello	gorilla	eyeball
	wig	hat	bone	snow
	wizard	magician	moth	prune