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Reverse Concreteness Effects Are Not a Typical Feature of Semantic Dementia: Evidence for the Hub-and-Spoke Model of Conceptual Representation

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The role of anterior temporal lobes (ATLs) in semantic processing is controversial. One theory, influenced by semantic dementia (SD) patients, is that this region is a pan-modal hub for all concepts. An alternative view is that atrophy in SD specifically affects knowledge for visual features. This is supported by reports of reverse concreteness effects in a few SD patients, suggesting that abstract word knowledge is spared relative to concrete words. However, it is not clear whether such effects are typical in SD, hence reliably associated with ATL damage, because most reports are of single cases and group studies have produced conflicting results. To address these contradictions, we investigated concreteness effects in 7 SD patients, using multiple tests from earlier studies in addition to new assessments. Comprehension was impaired for both word types but was better for concrete words. However, this pattern was not found uniformly across all tests and was most likely to be observed when: 1) concrete and abstract words were well matched for word frequency and 2) concrete and abstract words were selected with sufficient variation along the imageability scale. These factors account for the variability in previous studies and indicate that reverse concreteness effects are not common in SD.

Keywords: abstract, anterior temporal lobe, concrete, hub-and-spoke, semantic knowledge

Introduction

Semantic dementia (SD) is a progressive disorder in which atrophy of the anterior temporal lobes (ATLs) is associated with profound deterioration in conceptual knowledge. Due to its focal pattern of atrophy and highly selective neuropsychological presentation (other aspects of cognition, including phonology, syntax, visuospatial skills, and executive function are typically preserved until the late stages of the disease), SD is a critically important disorder for elucidating the neural basis of semantic memory and forms the foundation stone for the "hub-and-spoke" theory (Patterson et al. 2007; Pobric et al. 2010b). This model posits that conceptual representation arises from the interaction of modality-specific association regions (spokes) with a central, modality-invariant hub. Representations in the hub are sensitive to patterns of variation across multiple sensory modalities, which are necessary to code the complex nonlinear relationships between features and concepts (Lambon Ralph and Patterson 2008; Lambon Ralph et al. 2010). Accordingly, impairment in function of the hub accounts for the selective, multimodal semantic impairment seen in SD (Rogers et al. 2004). The focal atrophy in SD points to the inferior aspects of the ATLs as the site of the semantic hub, as both cortical atrophy and hypometabolism are centered on this region (Mummery et al. 2000; Gorno-Tempini et al. 2004; Williams et al. 2005; Nestor et al. 2006). In addition, 3 independent lines of evidence support this conclusion: 1) Repetitive transcranial magnetic stimulation (rTMS) applied to the lateral ATLs in healthy subjects produces a selective slowing for verbal and nonverbal semantic tasks (Pobric et al. 2007, 2010a; Lambon Ralph et al. 2009); 2) Functional magnetic resonance imaging (MRI) reveals inferolateral ATL activation for semantic tasks (Binney et al. 2010; Visser, Embleton, et al. 2010), provided various methodological issues are accounted for (see Visser, Jefferies, et al. 2010); and 3) neuroanatomical studies indicate that the ATLs are well placed to perform an integrating function due to their strong connectivity with multiple sensory association areas (Moran et al. 1987; Gloor 1997; Catani and de Schotten 2008).

An alternative account of SD holds that ventral temporal lobe atrophy affects modality-specific cortex that is crucial for coding the visual properties of objects (Breedin et al. 1994; Yi et al. 2007; Bonner et al. 2009, 2010; Macoir 2009). This view is supported by a series of reports of SD patients who show poorer comprehension of concrete words than of abstract words (Warrington 1975; Breedin et al. 1994; Cipolotti and Warrington 1995; Reilly et al. 2007; Yi et al. 2007; Bonner et al. 2009; Macoir 2009; Papagno et al. 2009). This intriguing pattern of performance, sometimes termed a "reversal of the concreteness effect" and which we will refer to as an A > C pattern, is in stark contrast to the processing advantage shown for concrete words by healthy participants (James 1975; Kroll and Merves 1986; Degroot 1989) and often found in aphasia following stroke (Coltheart 1980; Franklin 1989; Katz and Goodglass 1990; Hoffman, Jefferies, et al. 2010; Hoffman, Rogers, et al. 2010). The A > C effect suggests that knowledge of visual properties is disproportionately impaired in SD: visual information is thought to be integral to knowledge of concrete objects but is less relevant for abstract words, which may rely more on verbal associations (Paivio 1986). In contrast, the hub-and-spoke account provides no obvious explanation for A > C comprehension, since there is no reason to suppose that concrete concepts should depend on the hub to a greater extent than abstract concepts. In fact, in a recent rTMS study, stimulation of the ATLs in healthy subjects produced a more severe impairment for "abstract" words, suggesting that disrupting the hub produces a C > A pattern (Pobric et al. 2009).

It is important to note that, until recently, all reports of A > C effects in SD came from single-case studies. These studies are detailed and thorough and, in our view, leave little doubt that the concrete words can be disproportionately impaired, at least in a few carefully selected individuals. However, these isolated single cases give us no information about whether the A > C pattern of comprehension deficit is a "typical" feature of comprehension impairment in SD. It may be that A > C SD cases are rare and that they are overrepresented in the literature because they are a striking deviation from the expected pattern. This is an important clinical issue because at least one set of diagnostic criteria for SD include preserved knowledge of abstract words as a typical feature of the disorder (Grossman and Ash 2004). It is also key to theories of the neural basis for conceptual knowledge. If A > C effects are one of the cluster of symptoms reliably associated with SD, then any model of conceptual knowledge must be able to account for them. If, on the other hand, A > C effects are an idiosyncratic feature only found in a small subset of SD patients, then they should not form part of our general explanation of knowledge impairment in SD. Instead, we should ask what causes these occasional cases to deviate from the usual pattern.

In light of these concerns, 3 recent studies have explored concreteness effects in larger, unselected groups of SD patients. Yi et al. (2007) used a description-to-word matching task and found an A > C pattern for knowledge of verbs, with 9 of the 12 participants showing an effect in this direction. However, there was no such effect for noun knowledge. In a follow-up study, Bonner et al. (2009) tested 11 patients with a synonym matching task and found a similar A > C pattern at the group level (though the effects in both of these studies were much smaller those seen in earlier single-case reports). In contrast, Jefferies et al. (2009) gave a synonym judgment task to 11 SD patients and found a robust C > A effect across the group, a pattern that was present at a statistically significant level in all 11 individuals. Taken together, these studies give no clear answer to the question of whether the A > C pattern is reliably observed in SD. It is difficult to uncover the reason behind the conflicting results because each study used different patients, which may have differed in important ways (e.g., level of severity) and used different tests, which may have differed in terms of their demands and in the properties of the stimuli. In the present study, we investigated whether stimulus factors could account for the differences between studies. We directly compared several concreteness tests in a single set of 7 SD patients. This case series spanned the full range of severity observed in the disorder. The tasks used by Jefferies et al. (2009), Yi et al. (2007), and Bonner et al. (2009) were included, along with an existing task that probes associative knowledge (Shallice and McGill, unpublished data) and a new test designed to probe associative knowledge from pictures and words. In total, there were 436 observations per patient, making this to our knowledge the most detailed investigation of concreteness effects in SD to date.

By using multiple tests in the same set of patients, we were able to determine whether differences between tests could account for the contradictions in the literature. More importantly, by averaging results across multiple patients and multiple tests, we were able to assess the nature of concreteness effects in SD while avoiding distortions in the data caused by 1) the presence of 1 or 2 atypical patients or 2) the possibility that a particular test gave inconsistent results. In addition to assessing patient performance, we also examined the characteristics of the tests themselves with regard to 2 key psycholinguistic properties: word frequency and imageability. Word frequency strongly influences comprehension in SD, with more familiar words, and the concepts they refer to being less susceptible to degradation (Funnell 1995; Lambon Ralph et al. 1998; Jefferies et al. 2009). If this variable is not rigorously controlled, apparent A > C effects can emerge because abstract words tend to be more familiar than concrete words (Bird et al. 2000). Imageability refers to the ease with which a word elicits a mental image and thus distinguishes between concrete and abstract words. The more concreteand abstract words in a particular assessment differ in this respect, the more reliably the assessment will be able to reveal concreteness effects. (Although this is a minor point, it is worth noting that technically there is a distinction between "imageability," the ease with which a word elicits a mental image, and "concreteness," the degree to which it refers to a physical entity. In practice, the 2 measures are very strongly correlated ($r > 0.8$) and are used by most researchers interchangeably. We chose to use imageability values to analyse the tests because they are more commonly used in the literature and are more widely available than concreteness ratings).

Materials and Methods

Participants

Seven patients with a clinical diagnosis of SD were recruited from memory clinics in Bath, Liverpool, and Manchester, United Kingdom. Patients 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 nonverbal semantic deficits. Visuospatial skills, executive function, and day-to-day memory were relatively preserved. Imaging (MRI or CT) revealed bilateral ATL atrophy in all cases, although with a degree of asymmetry in each case. Four cases showed the more common pattern of greater atrophy in the left ATL, while 3 displayed more severe damage to the right ATL (see Table 1).

Patients completed a range of background neuropsychological tests, summarized in Table 1. To assess general cognitive function, the Addenbrooke's Cognitive Examination-Revised (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

Table 1
Background details and neuropsychological test scores

Test	Max	DF	MT	MB	PL	NH	PW	ET	Control mean (range)
Demographic									
Sex		M	F	F	F	F	M	F	
Age		64	61	61	72	68	73	80	
More atrophic temporal lobe		Left	Right	Left	Right	Right	Left	Left	
General neuropsychology									
ACE-R	100	78	79	72	56	45	41	43	93.7 (85–100)
Visuospatial									
Rey figure copy	36	36	36	33	31	21.5	34	23.5	34.0 (31–36)
VOSP number location	10	10	9	10	7	9	10	7	9.4 (7–10)
VOSP cube analysis	10	10	10	10	9	7	10	10	9.7 (6–10)
Attention/executive									
Digit span forward	—	7	7	6	8	5	5	7	6.8 (4–8)
Digit span backward	—	4	5	6	5	4	4	6	4.8 (3–7)
Raven's colored progressive matrices	36	34	35	32	31	16	34	29	
Cambridge semantic battery									
Naming	64	54	45	31	22	14	8	0	62.3 (57–64)
Word–picture matching	64	61	57	48	44	31	35	20	63.8 (63–64)
CCT pictures	64	55	45	41	30	26	34	28	59.1 (51–62)
CCT words	64	56	46	40	29	NT	NT	14	60.7 (57–63)
Category fluency (6 categories)	-	57	65	45	26	16	22	9	95.7 (61–134)

Note: ACE-R = Addenbrooke's Cognitive Examination-Revised (Mioshi et al. 2006); VOSP = Visual Object and Space Perception battery (Warrington and James 1991). CCT (Bozeat et al. 2000). NT = not tested.

Raven's colored 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 largely within the normal range on these tests, although 2 of the more severe patients were impaired in the Rey figure copy, and one also showed signs of poor executive function on the progressive matrices.

We assessed semantic knowledge with the Cambridge semantic battery (Bozeat et al. 2000; Adlam et al. 2010), 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: 1) picture naming, in which the 64 items were presented as black-and-white line drawings; 2) spoken word–picture matching, in the correct item must be selected from a field of 10 objects from the same category; 3) the Camel and Cactus Test (CCT), an associative matching task in which a concept is presented and a semantically related item is selected from 4 alternatives (e.g., which goes with camel: rose, tree, sunflower, or cactus?). The 4 choices were presented as pictures and as written words in separate tests; and 4) category fluency, in which the patient produced as many items from a given category as possible in 1 min. These tests revealed multimodal semantic impairments in all patients, with each failing at least 4 of 5 tests. Their scores revealed a broad spectrum of severity in semantic impairment, from DF who was very mildly impaired across all tests to ET whose picture naming was at floor and who was severely impaired on the other tests. Consequently, we were able to assess the status of concreteness effects at all stages of semantic impairment observed in SD.

Concrete–Abstract Tests

Patients completed 7 tests that contrasted concrete and abstract word knowledge. The first 5 had been used previously to compare concrete and abstract word comprehension and are described briefly below. The final 2 were designed for the present study and are described in more detail. All tests used a multiple-choice format but for a variety of different semantic judgments: word–word synonym matching, verbal description–word matching, and word–word and word–picture matching on the basis of semantic association. Thus a number of different types of semantic judgment were included, as were both verbal and pictorial stimuli, allowing us to ascertain the consistency of concreteness effects across multiple tests within the same set of patients. Where tests involved written words these were also read aloud by the experimenter. In all tests, patients were encouraged to guess if unsure of the answer. Example trials for each task are shown in Figure 1.

Synonym Judgment Task

This test was devised by Jefferies et al. (2009) and is illustrated in Fig. 1*C*. Patients were presented with a probe word and selected from 3 choices the word with a similar meaning. The foils were unrelated to the probe/target. The full test crossed 2 levels of frequency with 3 levels of imageability. However, to allow direct comparison with the other tests, we analyzed only the highest and lowest imageability conditions and collapsed across both levels of frequency. There were 64 trials in total, composed of 56 nouns, 5 adjectives, and 3 verbs. Words were presented in a written format and were also read aloud.

Description-to-Noun Matching Task

This test was devised by (Yi et al. 2007; and is illustrated in Fig. 1*A*). Patients were presented with a short definition and selected from 4 choices the word being described. The 3 foils were semantically related to the target but did not fit the description. Descriptions and choices were presented visually and read aloud and the test comprised 20 concrete and 20 abstract nouns. All stimuli were presented in writing and read aloud.

Description-to-Verb Matching Task

This test was devised by (Yi et al. 2007; and is illustrated in Fig. 1*B*). This had the same format as the previous test but featured verbs rather than nouns. They were divided into 2 conditions based on whether they were a verb of motion (e.g., run) or a verb of cognition (e.g., decide). Motion verbs were considered by Yi et al. (2007) to be more concrete and cognition verbs more abstract. There were 20 trials in each condition.

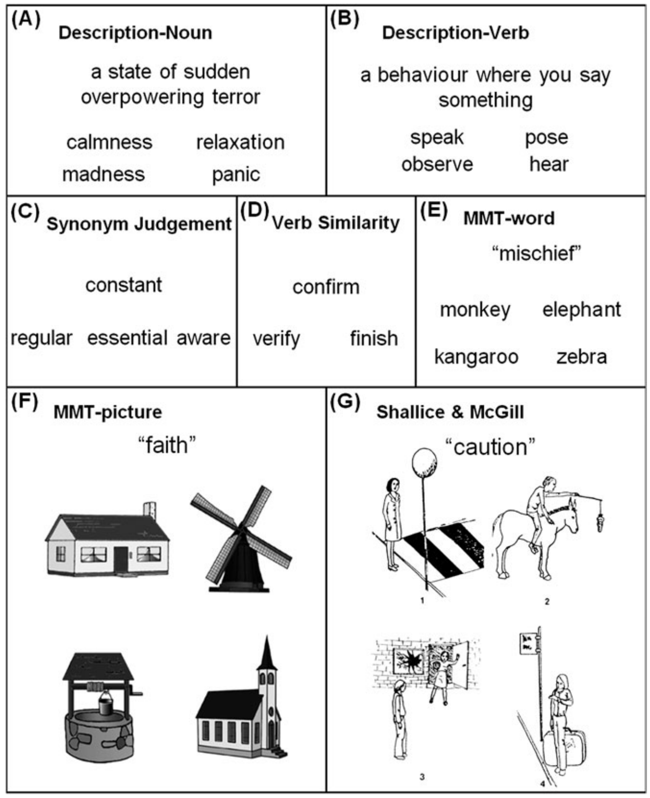

Figure 1. Examples of concreteness tasks. All examples are taken from abstract conditions.

Verb Similarity Test

This test was devised by Bonner et al. 2009 and is illustrated in Fig 1*D*. In this synonym matching task, 2 choices were presented on each trial and in each case, the target was strongly associated with the probe and the foil only weakly related. The full test contained 48 items but, following Bonner et al. we used only the 20 highest imageability and 20 lowest imageability items, yielding 40 trials. Words were simultaneously presented visually and read aloud by the experimenter.

Shallice and McGill (Unpublished Data) Word–Picture Matching Task

This test has been commonly used for a number of years to assess concreteness effects (e.g., Warrington and Shallice 1984; Breedin et al. 1994). A spoken word was presented to the patient and they selected a semantically related picture from 4 black-and-white line drawings. The relationship between the word and the picture was somewhat different for concrete and abstract words. In the concrete condition, the picture was simply the object denoted by the word (e.g., propeller → picture of a propeller). In the abstract condition, it was associated with the word or represented behavior associated with it (e.g., caution → picture of a woman waiting to cross a road). Accordingly, the abstract trials required a greater degree of inference and problem-solving ability. In addition, the images in this condition were more complex and often depicted scenes with multiple objects or people. There were 30 trials (all nouns) in each condition and there was also an emotion words condition that was not analyzed in the present study (Fig. 1*G*).

Mischievous Monkey Test with Pictures

This was a new test designed to use the same format as the Shallice and McGill test while avoiding the confounds described above. Patients were given a spoken word and matched it to an associated picture from a choice of 4. Each set of images consisted of 4 items belonging to the same semantic category. To design the tests, these were paired with a concrete noun and an abstract noun that were particularly related to one of the images (e.g., picture of a monkey → concrete: banana and abstract: mischief). The concrete and abstract words in each pair were matched for word frequency. During the task, each quartet of images was presented twice at different times: once with the concrete word and once with the abstract, with the spatial arrangement changed for the second presentation. Since the same sets of pictures were used in both concrete and abstract conditions, there were no differences in visual complexity or familiarity of the images. In a pilot study, 10 postgraduate students from the University of Manchester completed the test and rated each trial on a 5-point scale for the ease of selecting the correct picture and the strength of association between picture and word. These ratings did not differ for concrete versus abstract trials (ease: concrete = 4.2; abstract = 4.3; $t_{47} < 1$; association: concrete = 3.7; abstract = 3.6; $t_{47} = 1.2$, $P > 0.1$). The test contained 48 concrete and 48 abstract words. The test items are given in the Supplementary Material and the full test is available on the NARU website (www.psych-sci.manchester.ac.uk/naru/; Fig. 1*F*).

Mischievous Monkey Test with Words

This was an entirely verbal version of the previous task, constructed by replacing the pictures with written words. On each trial, the 4 words were presented visually and read out by the examiner and then the probe was presented in spoken form (Fig. 1*E*).

Analysis of Stimulus Characteristics

Frequency and imageability values were obtained for all of the probe words, targets, and foils used in the tests. We used lemma frequency counts from the CELEX database (Baayen et al. 1993), which were log transformed to reduce skew. To obtain imageability ratings for the largest possible number of words, we consulted 5 published databases: the Medical Research Council (MRC) Psycholinguistic Database (Coltheart 1981), the Bristol imageability norms (Stadthagen-Gonzalez and Davis 2006), and the ratings of Bird et al. (2001), Cortese and Fugett (2004), and Clark and Paivio (2004). All of these databases contained ratings on a 7-point scale, which were multiplied by 100 for ease of interpretation. When a word appeared in more than one database, an average was taken. Eight-two percent of the words used in the tests were available in at least one database.

Results

Patient Performance

Results

Mean performance on each task is shown in Figure 2 and the scores obtained by each patient in Table 2. To analyse concreteness effects across the entire group, we conducted a 2 × 7 repeated measures analysis of variance (ANOVA) with concreteness and task as the independent variables. (As PW was unable to complete the Mischievous Monkey Test with words [MMT-words] test, the mean for the rest of the group was used as his score on this test.) This revealed a main effect of concreteness ($F_{1,6}$ = 12.5, P = 0.012). Overall, patients performed better on the "concrete" conditions of the tasks. There was also a main effect of task ($F_{6,36}$ = 10.1, $P < 0.001$) and a concreteness × task interaction ($F_{6,36}$ = 4.85, P = 0.001), suggesting that the type of concreteness effect revealed varied across the different tasks. *T*-tests were conducted on the scores for each test to investigate the nature of the interaction in more detail. The synonym judgment task produced a highly significant C > A effect (t_6 = 10.5, $P < 0.001$). The C > A effect approached statistical significance in the Mischievous Monkey Test with pictures (MMT-picture) test (t_6 = 2.33, P = 0.058) and the Shallice and McGill test (t_6 = 1.88, P = 0.11). There were no significant differences between the 2 conditions for any of the remaining tasks. On the 2 description–word matching tasks there was a slight numerical advantage for abstract words, although this did not approach statistical significance in either case (description–noun: t_6 = 0.3, P = 0.82; description–verb: t_6 = 1.0, P = 0.36).

Chi-square tests were used to test for the presence of concreteness effects in individual patients (see Table 2). On the synonym judgment task, the 4 mildest patients showed a significant C > A effect. In the 3 remaining cases, the effect was in the same direction but was perhaps smaller because these patients were approaching chance levels of performance. There were also significant C > A effects for the 2 mildest patients on the Shallice and McGill test but none of the other tests revealed significant concreteness effects at the level of individual patients. When all tests were combined, the 2 mildest patients showed a significant C > A effect, as did one more severe patient. The numerical trend was for C > A in every patient except ET, who performed at chance levels on most of the assessments.

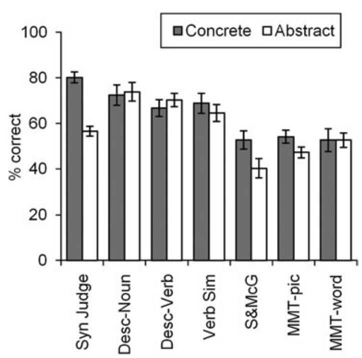

Figure 2. Mean accuracy on each task. Syn Judge = synonym judgment; Desc-Noun = description–noun matching; Desc-Verb = description–verb matching; Verb Sim = verb similarity test; S&McG = Shallice and McGill test. Bars indicate standard error of mean, adjusted to reflect the between-condition variance used in within-subject designs (Loftus and Masson 1994).

Discussion

Overall, patients showed better comprehension for concrete words, suggesting that A > C effects sometimes reported are not typical of SD more generally. However, there was some variation in the effects seen on different tasks, with the synonym judgment task producing the most robust C > A effect

Table 2
Individual patient performance on experimental tests

Test	Condition	Maximum	DF	MT	MB	PL	NH	PW	ET
Synonym judgment	Concrete	32	32*	29*	29*	29*	18	22	20
	Abstract	32	23	19	20	21	13	16	14
Description–noun	Concrete	20	19	19	12	19	10	14	8
	Abstract	20	19	20	13	17	12	9	13
Description–verb	Concrete	20	14	16	12	17	12	11	11
	Abstract	20	17	17	15	16	12	9	12
Verb similarity test	Concrete	20	19	15	9	17	11	13	12
	Abstract	20	15	14	11	18	11	11	10
Shallice and McGill	Concrete	30	29*	18*	15	19	10	10	9
	Abstract	30	17	10	15	12	11	9	10
MMT-picture	Concrete	48	35	34	30	23	20	23	16
	Abstract	48	36	27	26	25	18	17	9
MMT-word	Concrete	48	40	36	30	19	20	NT	11
	Abstract	48	40	32	28	22	18	NT	16
All tests	Concrete	%	88*	78*	62	72	48	57*	43
	Abstract	%	77	67	60	66	47	43	43

Note: *Indicates a significant C > A effect (chi-square 2-tailed $P < 0.05$).

and some other tests showing no difference between the 2 conditions. We did not replicate the A > C effects for verbs reported by Yi et al. (2007) and Bonner et al. (2009).

Correlations between Concrete and Abstract Word Impairments

The hub-and-spoke model predicts that impairment for concrete and abstract words will be strongly correlated since both word types are underpinned by a single semantic system. However, if concrete and abstract impairments have different underlying causes this correlation may be weak or absent. Despite the relatively small number of patients, we found a very strong relationship between mean concrete and mean abstract word performance ($r = 0.95$, $P = 0.001$; see Fig. 3). Correlations were also computed for each test individually; abstract and concrete knowledge was significantly correlated on all 7 tests ($r > 0.67$, one-tailed $P < 0.05$). We also investigated the relationship between severity of semantic impairment and the size of the concreteness effect in each patient. Some authors have suggested that unusual concreteness effects emerge as the disease becomes more severe (Bonner et al. 2010), while others claim that concreteness effects occur early in the disease before giving way to a more general deficit (Macoir 2009). As a measure of overall severity for each patient, we took the mean of the picture naming, word–picture matching, and picture CCT elements of the Cambridge semantic battery. There was no correlation between this severity measure and the size of the C > A effect ($r = 0.2$, $P = 0.67$).

Analysis of Test Characteristics

Rationale

Having administered various assessments in a single set of patients, we found considerable variation in the effects revealed by the different tests. While some tests revealed C > A effects, others showed no concrete–abstract differences. This suggests that differences in task characteristics could have led to the current discrepancies in the literature. To shed light on this issue, we examined the word stimuli used in each task, focusing on the 2 key psycholinguistic variables of frequency and imageability. Word frequency is a strong determinant of comprehension in SD and must be rigorously controlled to avoid potentially spurious results (Funnell 1995; Bird et al. 2000; Jefferies et al. 2009). Experimenters are usually careful to control for the frequency of the main probe words appearing in their tests (i.e., the words about which the patient is asked to make a semantic decision). However, multiple-choice tests also feature several possible matches to the probe. The frequencies of these foils and targets words are often not considered by experimenters, even though they also influence whether the patient responds correctly: patients are more likely to select the target and to eliminate the foils successfully if these are fully comprehended. Here, we analyzed the frequencies of the probe and choice words used in each test to determine whether there were any differences in word frequency between conditions that could bias the test toward producing a particular result. We also examined imageability ratings, which are judgments made by healthy individuals about how easily a word generates a mental image. They provide a quantitative measure of where words fall on the concrete–abstract spectrum. To be a sensitive indicator of concreteness effects, a test should maximize the difference between its concrete and abstract words on this measure. Highly concrete words should be associated with very strong mental images whereas it should be hard to generate much imagery at all for very abstract words.

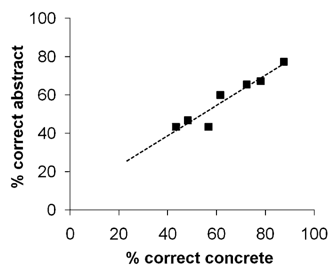

Figure 3. Scatter plot of patients' performance on concrete and abstract word comprehension.

Results

The top panels of Figure 4 show the frequency values for the probe words used in all tests (Panel *A*) and for the choice words for those tests with verbal choices (Panel *B*). (The MMT-picture and Shallice and McGill tests could not be included as they had pictorial choices and the MMT-word test because the same choice words were used in concrete and abstract conditions.) The Shallice and McGill test was the only one to show a large discrepancy between concrete and abstract words for the probes. On this test, abstract words were higher in frequency than the concrete words ($t_{57} = 3.73$, $P < 0.001$), whereas there were no frequency differences for any of the other tasks (all $t < 1.4$). The picture was different for the choice words. Here, both tests using verb stimuli featured abstract words that were significantly higher in frequency than in concrete words (verb similarity test: $t_{78} = 2.44$, $P < 0.02$; description–verb: $t_{118} = 2.07$, $P < 0.05$). This is in line with Bird

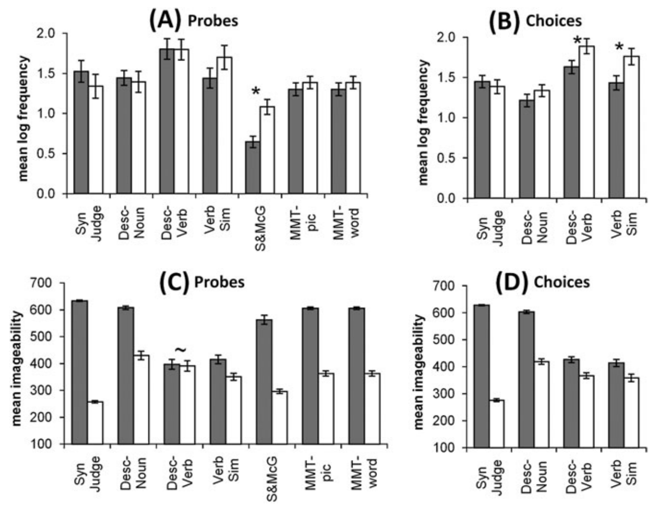

Figure 4. Frequency and imageability values for words used in the various tests. (*A*) and (*B*) show mean frequency values for probes and choice words. *Indicates that abstract words are significantly more frequent than concrete. Gray bars are concrete words and white bars are abstract words. (*C*) and (*D*) show mean imageability values for probes and choice words. ~Indicates no difference in imageability between concrete and abstract words (where no symbol is shown, concrete words were significantly higher in imageability). Syn Judge = synonym judgment; Desc-Noun = description–noun matching; Desc-Verb = description–verb matching; Verb Sim = verb similarity test; S&McG = Shallice and McGill test.

et al.'s (2000) observation that abstract verbs tend to be higher in frequency than in concrete verbs, which can produce confounds if not explicitly controlled. These confounds suggest that the Shallice and McGill test and the 2 verb tasks could reveal A > C effects in SD patients that are actually driven by differences in frequency, not concreteness. The 2 verb tests have previously revealed small reverse concreteness effects in SD case series (Yi et al. 2007; Bonner et al. 2009); it is possible, however, that these effects simply reflect uncontrolled differences in word frequency.

Imageability values for probe and choice words are presented in the bottom 2 panels of Figure 4. In this case, a clear distinction can be drawn between tests that used nouns as stimuli and those that used verbs. For all of the noun tests, probes in the concrete condition were much more imageable than those in the abstract ($t > 10$, $P < 0.001$). The synonym judgment task, however, had the largest difference in imageability values between concrete and abstract conditions, indicating that it is the most sensitive for detecting concreteness effects. In contrast, the verb similarity test showed a much smaller difference between concrete and abstract words (although it was statistically significant; $t_{30} = 3.0$, $P = 0.005$) and for the description–verb task, concrete probes were not significantly more imageable than abstract probes ($t_{30} = 0.22$, $P = 0.8$). Similar results were observed for the choices provided in each test. For the synonym judgment and description–noun tasks, concrete and abstract words were well separated along the imageability spectrum (synonym judgment: $t_{169} = 64.5$, $P < 0.001$; description–noun: $t_{89} = 15.8$, $P < 0.001$). Concrete and abstract choices on the verb tasks were much more similar in terms of imageability (although for both tests they did differ significantly; verb similarity test: $t_{63} = 2.97$, $P < 0.05$; description–verb: $t_{94} = 3.84$, $P < 0.001$). These differences in the strength of concreteness/imageability manipulations are another potential source of variability between tests. We analyzed the relationship between the size of the imageability manipulation employed by a test (difference in imageability between concrete and abstract words) and the size of the concreteness effect it revealed in the patients (difference in scores on concrete vs. abstract conditions). There was a significant positive correlation ($r = 0.78$, $P < 0.05$), indicating that larger C > A effects were seen for tests with more robust imageability manipulations.

Discussion

By analyzing the characteristics of the words used in each test, we identified 2 key stimulus factors that could explain discrepancies between tests. 1) Choice words in the verb tests were higher in frequency in the abstract condition relative to the concrete condition, indicating that these tests have a natural bias toward revealing apparent A > C effects. 2) The strength of the concreteness manipulation was much weaker in the verb tasks, indicating that they are less sensitive to genuine concreteness effects. The combination of these 2 factors might explain why previous studies that have used verbs as stimuli have found apparent A > C effects in SD: these tests were not very sensitive to detecting concreteness effects, allowing the frequency bias to boost comprehension in the abstract condition over the concrete. In contrast, the synonym judgment task combines a large manipulation of concreteness with good matching for word frequency and consistently reveals a typical C > A pattern of impaired comprehension.

General Discussion

We conducted a detailed case-series investigation of concreteness effects in SD, testing patients across the spectrum of disease severity. The study was motivated by a number of reports of individual SD patients who show reversed concreteness effects (Warrington 1975; Breedin et al. 1994; Cipolotti and Warrington 1995; Macoir 2009; Papagno et al. 2009). These reports are significant because they suggest that, rather than a central semantic deficit for all types of concept (Rogers et al. 2004; Patterson et al. 2007; Lambon Ralph et al. 2010; Pobric et al. 2010b), SD patients might have a specific deficit for visual feature knowledge that impacts mainly on concrete words (Breedin et al. 1994; Yi et al. 2007). The key question, which cannot be answered by isolated single-case reports, is whether A > C effects occur frequently enough to be considered part of the symptom complex reliably associated with SD. Recent case-series investigations using single assessments have provided conflicting answers to this question (Yi et al. 2007; Bonner et al. 2009; Jefferies et al. 2009). In the present study, 7 SD patients completed 7 tests of concrete and abstract knowledge. A reliable C > A pattern was found, which was consistent across all patients. This finding is consistent with the Jefferies et al. (2009) study and indicates that in most SD cases concrete words are not disproportionately impaired. Instead, a general semantic deficit affects both types of word but concrete words are slightly less impaired, in line with the processing advantage for concrete words seen in healthy individuals (James 1975; Kroll and Merves 1986; Degroot 1989). These results are in agreement with the effects of lateral ATL rTMS in healthy subjects (Pobric et al. 2009, which employed the same synonym judgment test used in this study) and with the view that bilateral ATL atrophy produces a general semantic deficit because this region is the key substrate for modality-invariant conceptual representations (Rogers et al. 2004).

By directly comparing the tasks used in earlier studies, we were able to identify 2 stimulus factors that accounted for the conflicting results in the literature. First, a robust manipulation of concreteness was necessary to reveal C > A effects reliably. Studies that have revealed A > C effects at the group level in SD contrasted motion and cognition verbs (Yi et al. 2007; Bonner et al. 2009), resulting in much smaller concrete–abstract differences in their test materials. Second, careful stimulus matching is necessary to avoid a confound in word frequency that can benefit abstract words. Because abstract verbs tend to be higher in frequency than concrete verbs, the abstract verbs used in previous studies have been more familiar to patients than the concrete verbs. This factor may have been instrumental in producing apparent A > C effects, as comprehension in SD is strongly influenced by word frequency (Bozeat et al. 2000; Jefferies et al. 2009).

Why Do the Majority of SD Patients Ahow a C > A Effect?

Of all the tests we analyzed, the synonym judgment task featured the largest imageability difference between concrete and abstract words and of the 18 SD patients who have completed this test in total (combining the present study and Jefferies et al. 2009) none have scored more highly for abstract words. On this basis, it is clear that the typical pattern in SD is for concrete words to be less affected than abstract words. Healthy individuals also show C > A effects in reaction times and accuracy for lexical decision (James 1975; Kroll and Merves

1986), reading (Strain et al. 1995), and comprehension tasks (Holmes and Langford 1976), suggesting that the performance of SD patients simply reflects an exaggeration of the normal pattern. One popular view is that concrete words enjoy a processing advantage because they have richer semantic representations (Paivio 1986; Plaut and Shallice 1993). In particular, Paivio's (1986) dual-coding theory states that concrete words are richer because they are associated with sensory information in addition to being coded verbally. Is this approach compatible with the hub-and-spoke model, which states that impairment in SD is a pan-modal deficit? On this view, the modality-invariant representations stored in the hub are distilled from inputs it receives from multiple modality-specific regions (Rogers et al. 2004; Patterson et al. 2007; Lambon Ralph et al. 2010). The input for abstract words comes primarily from perisylvian language areas, as the concepts referred to by these words are experienced only in the verbal domain. Concrete words, in addition to their verbal representations, are likely to be associated with input from a wider range of modality-specific "spokes" as they have tangible referents that are experienced in the environment (e.g., Pobric et al. 2010b). As concrete words are associated with richer and more varied sensory experiences they provide a stronger input to the modality-invariant hub, permitting richer representations to be formed that are more likely to resist degradation. Relatively preserved comprehension of words with rich sensory representations is therefore compatible with the hub account.

Why Do a Minority of SD Patients Show an A > C Effect?

Although it is now clear that the typical pattern of performance in SD is for C > A, there are a handful of SD patients in the literature who show clear and substantial reversals of this effect that are consistent across multiple tasks and stimuli (Warrington 1975; Breedin et al. 1994; Cipolotti and Warrington 1995; Macoir 2009; Papagno et al. 2009). What is special about these cases that causes them to deviate from the usual pattern? Here, we consider how behavioral and anatomical individual differences might give rise to A > C effects. From a behavioral perspective, it is possible that variation in premorbid experiences and educational background could influence how concrete and abstract words are affected by the disease. As discussed earlier, highly frequent or familiar words are less likely to become semantically degraded in SD. Individuals who are particularly familiar with abstract vocabulary (relative to most of the population) might be predisposed to show less impairment for these words. In these cases, the experimenter's careful matching for word frequency is sabotaged by the patient's atypical premorbid experiences. In Table 3, we list the occupations of patients who have shown large A > C effects as a consequence of SD and other etiologies. In most cases, they were professionals who would be expected to have above-average educational level and IQ. It could be that these individuals were particularly familiar with abstract terms and consequently these words were less affected by the disease than would usually be the case. However, whilst premorbid experience may explain many of the previous cases, it is unlikely to provide a complete explanation of reverse concreteness effects because not all highly educated SD patients show this pattern. One of the patients studied by Jefferies et al. (2009), for example, had a PhD yet displayed the same C > A pattern as the other cases.

Table 3

Occupations of patients showing large reverse concreteness effects

Study	Patient	Occupation	Etiology	More severely damaged hemisphere
Warrington (1975)	AB	High-level civil servant	SD	Unknown
Breedin et al. (1994)	DM	Professional with a Master's degree	SD	Left
Cipolotti and Warrington (1995)	DRN	Biological scientist	SD	Left
Macoir (2009)	SC	Psychology professor	SD	Left
Papagno et al. (2009)	MC	Teacher	SD	Left
Warrington and Shallice (1984)	SBY	Naval officer (engineer)	HSVE	Symmetric pathology
Sirigu et al. (1991)	FB	Engineering student and semiprofessional musician	HSVE	Symmetric pathology
Marshall et al. (1996)	RG	Chartered accountant (interests included opera and reading Dickens)	CVA	Presumed left
Warrington (1981)	CAV	Café owner	Glioma	Left

Note: HSVE = herpes simplex viral encephalitis and CVA = cerebral vascular accident.

In addition to individual differences in premorbid experience, there is also variability across patients in the extent and distribution of cortical atrophy. Atrophy in SD always affects the inferolateral aspects of the ATLs (Mummery et al. 2000; Galton et al. 2001), thought to be the site of the modality-invariant hub (Binney et al. 2010). However, there is inevitably variation across patients in the precise distribution and extent of cortical atrophy. Indeed, patients diagnosed with SD are occasionally found to have Alzheimer's pathology at post-mortem, which would be associated with a different pattern of degeneration (Hodges et al. 2010). Therefore, cortical atrophy can sometimes encompass other regions, including superior and posterior temporal regions that are associated with modality-specific spokes. There are 2 temporal lobe sites where an unusual distribution of atrophy in a particular patient could give rise to A > C effects in comprehension. First, the anterior portion of the superior temporal sulcus is associated with verbal comprehension (Scott et al. 2000; Sharp et al. 2004; Hickok and Poeppel 2007). It is also more active for abstract than concrete words in imaging studies (Sabsevitz et al. 2005), as would be expected if the meanings of 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 could be relatively preserved. The second key site is the ventral temporal lobe, posterior to the region of maximal atrophy in SD. This region is associated with visual feature knowledge for objects (Chao et al. 1999; Martin 2007) and is often more active for concrete words than abstract (Wise et al. 2000; Sabsevitz et al. 2005). Atrophy in this region is likely to affect concrete words to a greater extent than abstract words, again giving rise to an atypical A > C pattern in comprehension.

Finally, though ATL atrophy in SD is bilateral in almost all cases, it is often asymmetric with either the left or the right ATL bearing the brunt of the damage. It has been suggested that predominately left-sided atrophy leads to greater verbal semantic impairment while right-lateralized atrophy causes greater difficulty with nonverbal semantic knowledge (Snowden et al. 2004; Gainotti 2007). Could variation in the distribution of atrophy across left and right ATLs give rise to differences in the concreteness effect? One might assume that while abstract word knowledge depends exclusively on verbal knowledge, comprehension of concrete concepts depends on understanding of their verbal attributes and their nonverbal sensory characteristics. On this basis, one would expect damage to the right ATL to affect concrete word knowledge disproportionately because of the greater relevance of nonverbal semantic properties. This explanation is appealing because it links the atypical A > C comprehension pattern with the rarer right-sided presentation of SD (around 3 quarters of clinically presenting SD cases have greater atrophy on the left; Hodges and Patterson 2007). However, we can offer 2 pieces of evidence that run counter to this possibility. First, our review of previously reported A > C cases indicates that the majority, including all 4 SD cases for which anatomical data were available, had predominately left-sided pathology (see Table 3). Second, though the present study was not designed specifically to contrast left and right-sided atrophy in SD, our cohort happened to contain 3 patients with greater right ATL atrophy and 4 with the more typical left-sided pattern. There was no difference in the profiles of these patients with respect to the concreteness effects: the 3 right-sided cases (MT, PL, and NH) showed C > A effects of similar magnitude to the left-dominant cases. (We conducted a 2 × 2 ANOVA on performance averaged overall 7 tests, including concreteness as a within-subject factor and laterality of damage as a between-subjects factor. There was a main effect of concreteness ($F_{1,5}$ = 8.00, P < 0.05) but no effect of laterality ($F_{1,5}$ = 0.10) and no hint of an interaction ($F_{1,5}$ = 0.002). Though these results should be interpreted with caution due to the small number of cases, there is no evidence for any differences between left and right-sided cases.)

Conclusion

Striking reports of reverse concreteness effects in a handful of SD patients have led to claims that preservation of abstract word knowledge is a typical feature of the disorder. This suggests that loss of visual feature knowledge is key to understanding the condition and is less consistent with degradation of a pan-modal semantic hub. By investigating concreteness effects with multiple tests in a case series that covered the full range of disease severity, we have established that the typical pattern in SD is actually the opposite: comprehension of concrete words is slightly more preserved than that of abstract. This pattern was not seen uniformly across all tests, however, and 2 stimulus factors influenced whether it was observed. Tests that did not reveal a normal concreteness effect (and in previous studies have revealed apparent reverse concreteness effects) used higher frequency words to probe abstract word knowledge and employed less powerful manipulations of imageability. These factors can explain the conflicting results reported previously and, having taken them into account, there is no evidence that reverse concreteness effects are a typical feature of SD.

Supplementary Material

Supplementary material can be found at: http://www.cercor.oxfordjournals.org/

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