Declining object recognition performance in Semantic Dementia - a case for stored visual object representations

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Abstract

The role of the semantic system in recognising objects is a matter of debate. Connectionist theories argue that it is impossible for a participant to determine that an object is familiar to them without recourse to a semantic hub; localist theories state that accessing a stored representation of the visual features of the object is sufficient for recognition. We examine this issue through the longitudinal study of two cases of Semantic Dementia, a neurodegenerative disorder characterised by a progressive degradation of the semantic system. The cases in this paper do not conform to the "common" pattern of object recognition performance in Semantic Dementia described by Rogers et al (2004b), and show no systematic relationship between severity of semantic impairment and success in object decision. We argue that this data is inconsistent with the connectionist position but can be easily reconciled with localist theories that propose stored structural descriptions of objects outside of the semantic system.

Recognising that a visual object is familiar requires first that the visual features of the object are sufficiently processed and second that those features are successfully matched with knowledge stored in long term memory. In this paper, the term "recognition" is used to describe the process whereby an individual determines that they have encountered a particular stimulus before. The precise nature of the knowledge that is sufficient for object recognition as defined above is the subject of considerable debate in the literature. Key theorists can broadly be divided into two camps. One group, dubbed *connectionists,* consider that “*the ability to recognize objects from vision always draws upon semantic resources*” (Rogers, Lambon Ralph, Hodges, & Patterson, 2003, p. 627) - that is, success is predicated on successful retrieval of conceptual information - we must identify *what* an object is. The alternative *localist* position (e.g. Coltheart, 2004) is that recognition only requires identifying *that* an object is - it is not critical to retrieve the name of the object, to be able to categorise it or to understand its use as long as a matching visual featural representation can be found in memory. A representation cannot have been stored in memory if the object has not been encountered previously, thus finding a matching featural representation is only possible for familiar objects. The implication of this difference of theoretical views is that the latter assumes no necessary relationship between intact or impaired object recognition and intact or impaired conceptual semantics.

Traditionally, models of visual recognition posited that two types of representation are stored in long term memory (e.g. Hillis & Caramazza, 1995). The first of these provides a *structural* description of each particular object that belongs to a given object class. For example, a structural description of "chair" may include four vertical cylinders of equal length, a flat horizontal surface and a second flat surface that stands upright along one edge of the horizontal surface. The second type of representation is a conceptual *semantic* description of the object. In relation to our previous example, this would include information that the horizontal surface allowed the user to sit and that the upright surface provided back support to the person sitting on the object, which was called a "chair." Typically testing of object recognition and the stored structural description system involves the object decision task (e.g., Riddoch & Humphreys, 1987a). In this task, the participant must determine whether the picture they are presented with represents an existing object or a chimera - a non-existent object that is a recombination of parts from real items. For example, a chimera may combine the head of a goat with the body of a camel. In traditional cognitive neuropsychology, it was argued that success at this visual object recognition paradigm involves matching to structural descriptions in long term memory; no recourse to semantics is required. This suggestion of a separation between structural and semantic description systems was predicated on the performance of brain damaged patients with *agnosia*. Lissauer (1890) argued for a distinction between two forms of visual agnosia which relate to dysfunction at different stages of the perceptual process, and this notion has received support from researchers in the field (e.g. McCarthy & Warrington, 1986; Riddoch & Humphreys, 1987b; Warrington & James, 1988). The first is termed *apperceptive* agnosia, which relates to an inability to create a perceptual representation from vision. Patients with apperceptive agnosia perform poorly in tasks that require that they make discrimination on the basis of shape (e.g. Efron, 1968; Warrington & James, 1988) and without an adequate perceptual representation of the stimulus any attempt to process it for recognition or meaning is likely to be unsuccessful. The second type of visual agnosia is *associative* in nature. Cases with this presentation are able to perform normally in perceptual tasks (such as matching pictures of the same object from different viewpoints) but cannot associate the visual stimulus with meaning. Importantly, a number of published studies have described associative agnosic patients who were able to perform normally on the object decision task even though they were unable to access semantic information about visual objects (e.g. Carlesimo, Casadio, Sabbadini & Caltagirone, 1998; Hillis & Caramazza, 1995; Riddoch & Humphreys, 1987a). These authors have argued that in such cases the damage at the root of the disorder must be limited to connections between the visual system and the semantic system. Rogers et al. (2003), however, offered an alternative explanation. Specifically, they argued that damage to the semantic system causes the patient to lose specific knowledge of objects and instead fall back on the general conceptual knowledge that is preserved. As a result, they argue, patients may *appear* to be recognising visual objects in the normal range in spite of poor semantics when in actuality they are offering guesses based on the existence (or absence) of unusual visual features. We will examine this argument more closely below, after we have addressed the relationship between semantic performance and object recognition in the context of the neuropsychological presentation that is the focus of this paper.

In recent years, however, the independence of structural and semantic description systems has been called into question on the basis of studies of patients with Semantic Dementia (SD; Hodges, Patterson, Oxbury & Funnell, 1992; Snowden, Goulding & Neary, 1989). SD is a variant of primary progressive aphasia in which the focal impairment is of semantic memory, while other cognitive processes are left relatively intact. Several reports have demonstrated that the object decision accuracy of patients with SD is below the normal range and that the degree of object decision impairment is a correlated with the severity of semantic impairment in these cases (Patterson et al., 2006; Rogers et al., 2003). The above authors argue that these findings indicate that deficits in semantic processing are the keystone of poor performance in object decision. In short, object agnosia emerges as a consequence of conceptual semantic impairment. More generally, connectionists consider that damage to the semantic system will have an adverse impact on processing of input from any sensory modality (Rogers, Lambon Ralph, Garrard, Bozeat, McClelland, Hodges & Patterson, 2004). Using a computer simulation, they demonstrated that damaging a single semantic network, a transmodal "hub" for cognitive processing that acts to integrate information received from the brain areas that underpin the processing of input signals, can recreate the cardinal features of SD. The successful simulation of patient data in four tasks (picture naming, word-picture matching, categorization and delayed copying of pictures) was achieved without requiring that modality-specific "spokes" were damaged. Since Rogers et al.'s (2004a) model, data from neuroimaging studies have suggested that the patterns of activity in the bilateral anterior temporal lobes (ATL) are a good fit for the theoretical action of a transmodal semantic hub. Data from these studies has shown that the ATL are activated by semantic tasks irrespective of input modality and that these areas are not activated in non-semantic tasks of similar difficulty (see Lambon Ralph, 2014, for an overview of this research). Two crucial assumptions of this model are that a) damage to the semantic hub will adversely affect performance in all semantic tasks and b) that object recognition necessitates access to semantics, but that stimuli that are in some way unusual (or *atypical)* are more reliant on the function of the semantic hub (Patterson et al., 2006; Plaut, 2002; Rogers et al., 2003; Rogers, Lambon Ralph, Hodges & Patterson, 2004b).

However, there are several case studies reported in the literature concerning SD and object recognition that call into question the assumptions of the hub and spoke model. It has been shown that patients with semantic deficits do not necessarily perform poorly on tasks that connectionists argue rely on the semantic system. For example, AT (Hovius, Kellenbach, Graham, Hodges & Patterson, 2003) was a semantic dementia case who scored significantly below the normal range on spoken word-to-picture matching tasks requiring a level of object comprehension, but showed no impairment on object decision. This is at odds with an assumption that semantics must be accessed as a precursor to the recognition response. More compelling still are the reports of two patients (SB, Sheridan & Humphreys, 1993; RS, Samson & Pillon, 2003) who were able to recognise objects with the same level of accuracy as a healthy control sample even when the object decision task had been specifically constructed to include members of a category for which comprehension was impaired. SB, for example, was able to successfully verify the meaning of only 55% of sentences about foodstuffs (e.g. "Onions grow on trees") in a yes/no task, yet her accuracy was 96% when presented with an object decision task using foodstuffs and food-like chimera. In these reports the patients are able to recognise specific objects for which they cannot access semantic representations. Further, some cases in the literature (e.g. DJ, Fery & Morais, 2003) are able to access the semantic system from one modality but not another. DJ could understand written words but was not able to generate the meaning of visual objects.

Also of relevance to the debate regarding the relationship between semantic performance and object decision accuracy are the data from neuropsychological studies of individuals with "category-specific" semantic deficits. Such cases can show a selective impairment in comprehension of one class of objects (e.g. animals) while their access to semantic information about another class of objects (e.g. fruit/vegetables) remains intact. Some theorists (e.g. Caramazza, Hillis, Rapp & Romani, 1990) suggest that representations of items that share some meaning are clustered together in the semantic system, and that category-specific deficits reflect instances where the neural structures that hold the representations for only one cluster have been damaged. Other theorists (e.g. Humphreys & Forde, 2001) consider that a "semantic" deficit could reflect damage to the structural description system, because objects that have a similar meaning are also likely to share visual features. For example, the structural description of an animal may be likely to include four legs, a tail and fur. Thus an inability to identify these features will disproportionately affect objects in the animal category, sparing the ability to describe fruit and vegetables. Capitani, Laiacona, Mahon and Caramazza (2003) conducted a review of 79 published reports of patients with category-specific deficits in an attempt to examine these two positions and concluded that the structural description system operates relatively independently from conceptual knowledge. That is, it appears that category-specific semantic deficits arise from damage to the semantic system and are not artefacts of damage to other knowledge stores.

Given that category-specific semantic deficits indeed appear to be semantic in their locus, the connectionist position regarding object recognition would predict that an individual may exhibit difficulties in recognising *only* those objects for which they cannot access meaning. Caramazza and Shelton (1998) described the performance of EW on picture naming and object recognition tasks. EW showed a marked deficit in retrieving the names for animals using the Snodgrass and Vanderwart picture set, and a similarly clear deficit in distinguishing real from non-real animals in object decision. Her naming and recognition of non-animal stimuli was within the normal range. EW, therefore, performs exactly as the connectionist framework expects. Again though, this association between semantics and object recognition is not universal amongst cases with category-specific deficits. Blundo, Ricci and Miller (2006), for example, reported the case of KC who also showed a deficit in naming the animal items from Snodgrass and Vanderwart but showed no difficulty in distinguishing pictures of real animals from chimaera. According to *localist* theories, typified by Coltheart (2004), this dissociation between patterns of performance in semantic and visual tasks is possible because of modality-specific stores of the visual forms for all stimuli that are familiar to the participant. This model suggests, therefore, that it is possible to recognise an object on the basis of the visual features of the input (stored structural representations for objects – stored orthographic representations for words). Thus it is possible for the semantic system to become damaged (as it does in SD) without *requiring* any impairment in object decision, provided that the stored structural representations remains intact (see Coltheart, Saunders & Tree, 2010 for a discussion of this principle in relation to visual *word* recognition).

Rogers and his colleagues (2003; 2004b) have suggested mechanisms by which object decision performance can remain good in the face of semantic impairment despite the assumptions of their model – and thus attempt to account for the contrary evidence discussed earlier. Their position is that information is encoded through the weights of connections between parts of the cognitive network and that these weights are affected by individual experience. That is, pairs of input and output that are encountered often are associated by stronger connections. The strength of a given connection may be increased either by accessing that specific stimulus or because of overlap with other items in the same category. Thus, according to Rogers et al (2003; 2004b), object decision can remain accurate when the target is *typical* of the category and the distractor is not or when the target itself is highly familiar. In essence then, these authors argue that object decision performance (successful or otherwise) is *confounded* with this typicality variable – such that 'intact' performance may in fact simply reflect stimulus selection that was insufficiently rigorous. To attempt to confirm this, Rogers et al created a two-alternative forced-choice version of the object decision task. In this task the participant is shown a picture of an object and a chimera at the same time, and is asked which of the stimuli is real. Targets can be of high or low familiarity and pairs of stimuli vary in terms of how "typical" they are of that category of objects. For example, most members of the "animal" category do not have horns at the end of their noses. Thus a rhinoceros is a real animal that is *less* typical of the animal category than a version of the rhinoceros depicted without the horn; a donkey is a real animal that is *more* typical of the animal category than a picture of a donkey with a horn added. Rogers et al (2004b) showed that, in a group of SD patients, target familiarity interacted with the typicality factor. High familiarity targets were recognised accurately irrespective of whether they were more or less typical than the chimera. When the target was not commonly encountered, however, patients made a greater number of errors when the chimera was the more typical of the category. The authors argued that in the face of semantic impairment, SD cases become dependent on general (or 'default') properties when performing object decision tasks. Moreover, this dependence increases in the face of further semantic memory deterioration - thus the size of the interaction likely increases during disease progression as the semantic deficit becomes more severe. Rogers et al (2004b) therefore offered an explanation for preserved object decision performance in SD without the need for representations of visual forms in a pictorial lexicon.

It should be noted, however, that the pattern reported by Rogers et al (2004b) is by no means incompatible with theories that propose a visual object lexicon - under the localist framework both the effects of familiarity and visual overlap with other known objects can be seen as lexical effects. Related to this issue, Grainger and Jacobs (1996) argued that correct word recognition responses can occur either because the stimulus is an exact match to a stored visual representation, or because the stimulus looks like it *could be* a real exemplar. In the absence of an exact match for the input, participants may guess that they ought to recognise the stimulus on the grounds that there are sufficient overlapping features with familiar words. A similar decision process may well be applied to object decision. High familiarity targets would be recognised because a matching representation could be determined from stored structural descriptions. When targets are low familiarity, and hence an exact match cannot be found quickly, any features that overlap with other known objects will increase the activation of currently stored structural descriptions. The participant is likely, therefore, to guess at the more typical of the two presented options. Although this process may produce an interaction between familiarity and typicality, it does not necessarily implicate semantics in the size (or even the existence) of the interaction.

Another interesting theory of the potential relationship between semantic performance and object decision accuracy was offered by Zannino, Perri, Caltagirone and Carlesimo (2011; also Zannino, Perri, Monaco, Caltagirone, Luzzi & Carlesimo, 2014) who argued that performance in object decision tasks will decline in SD *until* the damage to the semantic system reaches a catastrophic level, at which point accuracy will improve. Zannino et al (2011) suggested that there are two possible ways to complete an object decision task; a visual strategy and a semantic strategy. In their view, objects can be recognised via accessing modality-specific visual representations. However, the default strategy for object (and indeed word) recognition responses is to rely on a semantic hub. In SD the semantic system has become compromised, so the use of a semantic strategy relies on faulty information and is thus inaccurate. By contrast, agnosia is characterised by a disconnection between modality-specific visual representations and the semantic hub, and this disconnection precludes the use of a semantic strategy. Agnosics therefore perform object decision tasks via a visual strategy which enables accuracy in these cases to remain good. If we take this theory to its logical conclusion, it is possible to suggest that SD disease progression will eventually damage the semantic system to such an extent that it becomes "pathologically disconnected" (Zannino et al., 2001, p. 2113) from the modality-specific representation system. This leads to a particularly interesting prediction - that at some point the object decision performance of SD cases may dramatically improve following an initial decline. Such a prediction can only be assessed through longitudinal study.

This study is a longitudinal assessment of two SD cases, directly comparing semantic performance and corresponding ability to perform object decision. The three theories outlined above make distinct predictions about the relationship between comprehension and recognition tasks. The hub and spoke model predicts that as semantic ability decreases so too will object decision accuracy, and that interactions between target familiarity and object typicality will be greater when semantic processing is more severely compromised. Zannino et al's (2011) work suggests that this may not be the case throughout the disease progression, and that beyond a certain level of semantic impairment (once a pathological disconnect has occurred) object recognition performance may return to normal or near-normal levels. Coltheart's (2004) position is that there need never be a relationship between object recognition performance and semantic ability provided that separately stored object structural representations remain intact.

Method

Case summaries

When we started to collect the data described in this paper, JD was 59 years old. The background to her diagnosis and her performance on a number of different cognitive tasks have been described elsewhere (e.g. Playfoot, Izura & Tree, 2013; Playfoot, Tree & Izura, 2014). JD had deficits in semantic processing tasks (e.g. Pyramids and Palm Trees, Howard & Patterson, 1992), but her performance on tests of basic visual processing were within the normal range. She exhibited no difficulties in tests of grammar processing (Test for Reception of Grammar, Bishop, 1982), rhyme judgement, phonological segmentation, word or non-word repetition (from Psycholinguistic Assessment of Language Processing in Aphasia, Kay, Lesser & Coltheart, 1992).

NJ (born 1948) first approached the researchers in 2002 after referral by their GP regarding word-finding difficulties (anomia). Although at that point mild, NJ was a highly articulate individual (with a PhD in English Literature) and a wealth of experience in public speaking (both as a lecturer and amateur actor/play-write) and thus he felt there was a cause for concern. Past medical history suggested no previous neurological injury, or other complicating medical factors – family history was also unremarkable, with no history of similar dementia in recent memory and no evidence of general anxiety and/or depression. Over subsequent years NJ's anomia markedly worsened, and additional comprehension difficulties began to emerge. By 2005, based on his behavioural profile and radiological investigations (indicating bilateral temporal atrophy), NJ was given a clinical diagnosis of semantic dementia and he had retired from his work as a lecturer – despite his increasing deterioration in language abilities, NJ remained an excellent artist and draftsman – exhibiting work in the local area for a number of years after diagnosis. There was also no evidence of a general deterioration in other cognitive processes, and NJ should no impairment in general activities of everyday living. Prior to the commencement of this study, he performed in the normal range on tests of visual processing, rhyme judgement, segmentation, repetition and grammatical processing (on the same tests as for JD, above). Table 1 presents the baseline performance of both cases on the critical tests for this paper, alongside descriptive statistics for a group of healthy control participants (N = 14, 10 of whom were female, mean age = 63.5 years, SD of ages = 3.5) recruited as part of the current study.

(Table 1 about here)

Materials

We used three different tests in total. The Pyramids and Palm Trees (Howard & Patterson, 1992) presents participants with a picture cue and asks them to indicate which of two possible target pictures is semantically related to the cue. This task was administered to track the semantic decline caused by the progression of the dementia in our cases. As a measure of basic visual processing ability (to rule out an apperceptive agnosia), JD and NJ were asked to complete the Foreshortened View and Minimal Feature tasks from the Birmingham Object Recognition Battery (BORB, Riddoch & Humphreys, 1993). The critical measure used in the current study was the Over-Regular Object Test (OOT; Rogers et al., 2004b). This task presents participants with pairs of line drawings. One picture in each pair is an existing object. The second picture is a chimera, where the existing object has had one distinguishing feature altered. The participant is required to indicate which of the two pictures is real. Target objects vary on the basis of familiarity. The important manipulation in this task is that the objects vary also in their "typicality" - the degree to which this particular object matches with the features of the other objects in that class. For example, a "typical" animal has relatively small ears. Thus a drawing of a chimeric elephant with small ears is more typical of the "animal" category than a drawing of a real elephant with large ears. The OOT contains 30 pairs such as this, where the real object has a feature that is atypical of the category that the non-real item does not (these are known as the NR > R items). The OOT also contains 30 pairs in which the real item is more typical of the category than the non-real item (R > NR trials). For example, real monkeys have small ears so an accurate drawing of a monkey is more typical of "animal" than a chimeric monkey with large ears.

Procedure

JD performed the above tasks on 5 occasions. The test periods were roughly a year apart. For NJ, there were 4 test sessions. A year separated the first two sessions, and the tasks were repeated every 6 months thereafter. In any given test session the BORB, OOT and semantic tasks were performed in a random order. All stimuli were presented on a laptop computer screen, and instructions and encouragement were provided verbally. Interestingly both cases said they felt they were guessing when presented with the OOT - this was true for all sessions.

Results

The longitudinal performance of each of our cases on each of the tasks is presented in Table 2. It appears from this table that a) semantic performance decreased for both JD and NJ and b) that basic visual processing performance and object decision performance remained fairly stable over time. The following sections analyse these data more formally with regard to specific research questions. Firstly, we examined whether either of our cases presented an apperceptive agnosia at any point. Secondly, we assessed the point at which their semantic performance became significantly impaired, and whether this ability continued to decline. Finally, we examined performance on the OOT to determine when performance became impaired versus controls, whether the pattern of impairment matched the pattern reported by Rogers at al. (2004), and whether there was a systematic relationship between performance on this tasks and the degree of semantic impairment. All descriptive statistics are presented in Table 2.

(Table 2 about here)

In what follows we used Crawford's t-test (Crawford & Howell, 1998) to compare patient performance with that of healthy controls on each task. McNemar's tests were used to formally assess changes in accuracy for each of our cases in consecutive sessions. Finally we used chi square analyses to examine accuracy across stimulus types and to compare the performance of JD and NJ.

Visual impairment and apperceptive agnosia.

We compared the performance of each of our cases on two subtests of the BORB battery with data from the normative population reported by Riddoch and Humphreys (1993) in the publication of the tests. Results indicated that both of our cases performed in the normal range throughout the testing period for both BORB tasks (all $p > .1$). These findings make it unlikely that any errors made in object decision stemmed from deficits in basic visual processing.

Semantic performance

Semantic performance (as measured using Pyramids and Palm Trees) was already impaired for NJ at initial testing [$t(13) = 10.881$, $p < 0.01$], and JD was significantly impaired from session 2 [$t(13) = 6.741$, $p < 0.01$] versus our healthy control group. Performance continued to decline significantly for JD and for NJ over the duration of the testing period. JD's accuracy was significantly poorer in the second session than it had been in the first [$X^2 (1) = 5.1429$, $p < .05$]. By the final session, JD had dropped from 96% to only 62% on this task - a significant overall decline [$X^2 (1) = 14.45$, $p < .001$]. Although NJ's accuracy decreased from one session to the next across the whole testing period, only the drop between consecutive sessions was observed between the third and the final session [$X^2 (1) = 4.5$, $p < .05$]. His overall score on the semantic task decreased by a significant 21% over the 4 sessions [$X^2(1) = 12$, $p < .001$].

Object Decision

In Rogers et al's (2004b) original report on the OOT, the semantic dementia cases they studied made the greatest number of errors in trials where the chimera was more typical of the category than the target, and the target itself was of low familiarity. This pattern was exacerbated in cases with more severe semantic deficits. According to this position, our patients ought to show impairments on low familiarity NR > R trials earlier in the disease progression than high familiarity NR > R trials, and may remain relatively unimpaired in R > NR trials until later test sessions.

Analyses indicated that JD was not significantly impaired for high familiarity NR > R or low familiarity R > NR trials at in any session (all $p < .1$). She performed significantly worse than controls for the high familiarity R > NR trials from the penultimate session [$t(13) = 3.531$, $p < 0.01$] and again in the final session. JD's recognition of objects in the low familiarity NR > R trials remained in the normal range until the final session, whereupon it became impaired [$t(13) = 4.034$, $p < .001$]. This is not the pattern that would be expected according to Rogers et al (2004b) - in fact JD's object decision performance remained good long after the semantic system had been compromised.

NJ performed at ceiling for all trial types in the first test session. He showed significantly poorer object decision performance than controls for high familiarity NR > R trials from session 2 [t(13) = 5.560, $p < 0.001$]. He dropped significantly below the normal range for high familiarity R > NR trials in session 3 [t(13) = 3.531, $p < 0.01$] but returned to the normal range thereafter. His accuracy in low familiarity NR > R and low familiarity R > NR trials remained normal until the final session [t(13) = 5.872, $p < 0.001$ and t(13) = 4.649, $p < 0.001$, respectively]. This is also a marked departure from the pattern reported by Rogers et al (2004b). JD's accuracy did not decrease significantly for any trial type across any adjacent sessions, and neither did NJ's (all $p > .1$).

Rogers et al (2004b) reported that the accuracy of the semantic dementia cases that they tested on the OOT showed an interaction between target familiarity and object typicality. Specifically, accuracy in their sample tended to be high when the target object is more typical of that category that the foil - this was true irrespective of how frequently the target object was encountered in itself. Accuracy dropped significantly when the target was less typical of the object category than the chimera, and a greater decrease in performance was observed when the target was unfamiliar than when it was a common object. As can be seen in Figure 1, neither of the cases we describe in this paper showed the pattern Rogers et al (2004b) reported consistently. In fact, only in the fourth session with NJ does the object decision performance data represented in the figure look anything like the interaction between typicality and object familiarity that Rogers et al described.

We used chi square to examine these data more closely. As JD performed at ceiling for low familiarity R > NR trials throughout, no formal analyses including this condition could be computed, and neither could comparisons with any trial type for which JD achieved 100% in a given session. Analyses indicated that, with one exception, JD performed statistically similarly in all conditions and in all sessions. In her final session, her accuracy for low familiarity NR > R was significantly poorer than for high familiarity NR > R trials [$X^2(1) = 6.166$, $p < .05$].

NJ performed significantly worse in high familiarity NR > R trials than he did in all other conditions in the third session [all $X^2(1) = 12.792$, $p < .001$]. Responses in high familiarity NR > R trials remained significantly less accurate than for low familiarity R > NR and low familiarity NR > R trials in session 4 [$X^2(1) = 6.166$, $p < .05$ in both instances], but was not significantly different from high familiarity R > NR trials [$X^2(1) = 1.306$, $p > .1$]. In the final session, NJ's showed a typicality effect, but not a familiarity effect, and no interaction between the two factors. His accuracy was statistically equivalent in R > NR trials irrespective of familiarity [$X^2(1) = 1.389$, $p > .1$]. Accuracy in high familiarity R > NR trials was significantly better than in high familiarity NR > R trials [$X^2(1) = 6.166$, $p < .05$]. Accuracy was also significantly better in low familiarity R > NR trials than in low familiarity NR > R trials [$X^2(1) = 5.281$, $p < .05$].

(Figure 1 about here)

In summary, neither case ever showed the pattern reported by Rogers et al (2004b). In the final session, NJ showed an effect of typicality, but not of familiarity, and no interaction; JD showed an effect of target familiarity, but only limited to NR > R trials.

The nature of neuropsychological case study methodology, such as ours, is that there are insufficient data points available to formally assess the relationship between semantic performance and object decision scores using correlation or regression methods. Nevertheless, we wanted to statistically analyse this relationship. Rogers et al.'s (2004b) argument is that there is an association between semantic ability and object decision performance. That is, object decision accuracy should decline roughly in line with semantic performance. Hence the difference between PPT score and OOT scores should not be greater in our cases than is possible in a control sample. By that logic, if a dissociation can be determined it is unlikely that the same underlying cognitive system is being used for both tasks. Crawford and Garthwaite (2007) developed the Bayesian Standardized Difference Test, which allows for the formal examination of whether a single case exhibits a dissociation between ability on two tasks. This test determines a) whether an individual is impaired on task X, b) whether the individual is impaired on task Y and c) whether a difference between performance on tasks X and Y as large as that exhibited by the test case is likely to occur in a control population. The test takes into account normal performance on each task and the correlation between scores on task X and Y in a control group is incorporated into the calculation. Importantly, this test has been shown to allow only a small number of Type 1 errors, even if the distribution of control scores is severely skewed (as it is likely to be in neuropsychological testing). Further, the Bayesian Standardized Difference Test is able to take into account the severity of the patient's impairment in the tasks, becoming more conservative when the impairment is greater.

Crawford and Garthwaite (2007) define two types of dissociation between scores on a pair of tests. The *classical* dissociation is observed when a patient scores in the normal range for one test while scoring significantly below controls for the other test. That is, a patient who is unimpaired for test X but impaired for test Y exhibits the classical dissociation. A *strong* dissociation is observed when a patient is impaired for both tests relative to a control sample, but their deficit is significantly greater for one test than the other. The computation of the Bayesian Standardized Difference Test indicates whether a neuropsychological case fulfils the criteria for either a classical or a strong dissociation and provides a p value for the likelihood of a member of the control sample showing a discrepancy between test scores as extreme as the patient. We ran the Bayesian Standardized Difference Test on observations from JD and NJ in each test session, comparing their performance to out 14 healthy controls. In each instance, we included semantic performance (PPT) and *one* of the conditions of the object recognition task. Table 3, below, summarises the findings of these analyses.

(Table 3 about here)

JD was not impaired on either semantic or object recognition tests in the first test session. With these exceptions, both JD and NJ showed significant dissociations between accuracy on Pyramids and Palm Trees and the OOT in *every* condition and every test session. A few other observations about the relationship between semantic performance and object decision accuracy should also be highlighted here. Firstly, at some point in the data collection both of our cases scored 69% on the Pyramids and Palm Trees task. This provides a useful point of comparison between JD and NJ, and a means to examine the hypothesis that semantic ability is a key determinant of object decision performance. When both cases scored the same on the semantic measure, JD outperformed NJ for high familiarity NR > R trials [$X^2(1) = 12.792$, $p < .001$]. Secondly, in the penultimate and final sessions, NJ scored the same for Pyramids and Palm Trees (58% correct), yet his performance in low familiarity NR > R object decisions dropped by 20%. Taken together, these results suggest that the relationship between semantics and object decision is far more complex that argued by Rogers et al (2004b).

Discussion

We administered tests of semantic ability, visual processing and object decision to two cases of SD in a longitudinal study to assess the relationship between semantic decline and object recognition performance. Our main findings can be summarised as follows; although both of our patients showed considerable decline in semantic ability over time and both performed below the normal range in object decision for at least some types of stimuli during the test period, there was no predictable relationship between semantics and object recognition accuracy. We acknowledge that the picture version of the Pyramids and Palm Trees test requires the use of both the structural description system and the semantic system proposed by localist theories. As a result our measure of semantic ability is not fully independent of visual object recognition. However, in instances where the "semantic" deficit was the result of error in the structural representation system, the relationship between Pyramids and Palm Trees score and object decision score would have been increased. Further, as neither of our cases exhibited problems in tests of basic visual perception it is unlikely that either a) poor performance on Pyramids and Palm Trees or b) the dissociation between semantic ability and object decision performance in our cases was the result of apperceptive issues.

These findings are not easily reconciled with the connectionist theory that recognising an object as familiar necessitates recourse to semantics. According to the hub and spoke model (Rogers et al, 2004a), the regions of the brain that are specialised to accommodate input from each sensory modality create transitory representations which are then integrated and interrogated by a transmodal semantic hub. As the modality-specific areas in this model do not store long term representations the only mechanism for recognising familiar objects is the semantic system. As a consequence, damage to the semantic "hub" system as occurs in SD ought to result in poor object recognition performance, and the more severe the damage the greater the deficit (Patterson et al., 2006; Rogers et al., 2003). This is not evident in our data. Firstly, in sessions where JD and NJ had equivalent scores on the Pyramids and Palm Trees task they were significantly different in their object decision accuracy. Secondly, in two consecutive sessions NJ scored the same on Pyramids and Palm Trees but his object decision accuracy was far lower in one session than the other. At the very least, this indicates that the integrity of the semantic system is not the sole determinant of successful object recognition. Such a finding can be accommodated by a localist theory (e.g. Coltheart, 2004) in which object recognition relies on accessing a stored representation of the visual features of familiar objects from a store of structural descriptions. In this framework it is theoretically possible for the semantic system to become damaged without the structural descriptions being compromised at all. Thus a case with significant semantic dysfunction may still perform normally in object decision, and no consistent relationship between semantic performance and object recognition is predicted.

Rogers et al (2003; 2004b) argued that both the familiarity and the visual typicality of an object can impact on the likelihood of recognising it in a two-alternative forced choice task - that is, that the presence of an effect of semantic ability on object decision performance could be confounded by other factors. To reiterate from the introduction, the position of Rogers et al is that meaning is represented by the weights of connections in a distributed network, and that the weight of each connection is affected by individual experience. Stronger links exist between pairs of inputs and outputs that are frequently encountered. These links could reflect a well-practiced coupling of a single input with a single output (as in high familiarity objects) or because the link is relevant to a large number of different stimuli from the same category. In this framework, damage to the semantic system is most likely to adversely affect responses to objects that are neither commonly encountered nor typical of the category (Patterson et al., 2006; Plaut, 2002; Rogers et al., 2003; Rogers et al, 2004b). Again our data do not match with this prediction. Neither of our cases ever showed the interaction between familiarity and typicality reported by Rogers et al (2004b). JD performed equally well irrespective of target familiarity and irrespective of which member of the pair was more visually typical of the target category. NJ was affected by typicality but not by familiarity. In addition, the presence or absence of these effects was not tied to the level of semantic dysfunction. We demonstrated, in fact, that both of our cases showed strong or classical dissociations between semantic performance and object recognition accuracy - that is, the discrepancy in their scores on these two tasks was greater than that expected in a healthy control population. In each case, performance was significantly worse in the test of semantic ability than in object decision. This pattern of performance can also be accommodated by a localist theory that does not implicate semantics in object recognition, but pose questions for a theory in which the semantic system is integral to object recognition.

Zannino et al (2011) suggested that object recognition could be accomplished either by recourse to semantics or by accessing a modality-specific representation in long term memory. They argued that the default strategy when performing object decision tasks was to rely on the semantic system unless this was pathologically disconnected from the modality-specific system (as in visual associative agnosia). On this assumption, the performance of SD cases in object decision tasks should initially decline in line with the severity of the semantic damage because their responses are based on the activation of a faulty system. As above, our data do not support a linear relationship between semantic ability and object recognition performance. Zannino et al's (2011) position, if taken to a logical conclusion, would suggest that if the damage to the semantic system became sufficiently extensive to preclude its use in object recognition then performance on object decision may improve later in disease progression - once the semantic system is no longer a viable option the patient will begin to use the modality-specific representations instead. Although our data do not support this prediction our findings do not rule out the potential for object decision accuracy to ultimately improve. It could simply be that neither of the cases described in this paper had semantic damage severe enough to force them to switch to the modality-specific strategy to perform the task. However, we consider that this is not likely given that there was no predictable relationship between semantic ability and object decision accuracy. We argue that object recognition in JD and NJ is not based on the semantic system and instead relies on modality-specific object based stored structural representations – which have become impaired to varying degrees for both cases during disease progression. Given we assume no necessary dependence on the semantic system, there is no need for a 'strategy switch' to emerge and hence we would not expect an improvement in performance at any stage during disease progression.

Taken together, our findings call in to question the assumptions of connectionist theory, but are readily reconciled with localist theories which propose the existence of a pictorial lexicon (e.g. Coltheart, 2004). We argue that object decision does not necessitate semantic activation to be successful, and that instead the identification of a modality-specific representation that matches the visual features of the stimulus is sufficient for recognition.

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Table 1 - Percentage correct in baseline neuropsychological tests JD and NJ. Healthy control participant performance is also included (SD in parentheses)

	JD	NJ	Controls (N=14)
Pyramids and Palm Trees	96	73	98 (2.16)
BORB - Foreshortened	96	100	97 (3.52)
BORB - Minimal features	100	96	98 (2.51)
Digit Span (forward/backward)	9/6	9/6	-

Note: BORB = Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993), Pyramids and Palm Trees (Howard & Patterson, 1992).

Table 2 - Accuracy data (%) for JD and NJ, along with healthy control performance (SD provided in parentheses).

		JD					NJ				
		2008	2009	2010	2011	2012	Late 2007	Late 2008	Early 2009	Late 2009	Controls (N = 14)
Semantics	PPT	96	83	81	69	62	73	69	58	58	98 (2.16)
Visual Processing	BORB - Foreshortened	96	100	92	80	80	100	92	88	100	97 (3.52)
	BORB - Minimal features	100	100	92	96	92	96	100	96	96	98 (2.51)
Object Decision	OOT High Familiarity R>NR	100	93	93	87	87	100	93	87	93	98 (3.13)
	OOT High Familiarity NR>R	93	100	93	93	93	100	73	80	80	98 (4.22)
	OOT Low Familiarity R>NR	100	100	100	100	100	100	93	93	87	99 (3.86)
	OOT Low Familiarity NR>R	93	93	100	93	80	100	93	93	73	98 (4.08)

Note: PPT = Pyramids and Palm Trees (Howard & Patterson, 1992). BORB = Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993). OOT = Over-Regular Object Test (Rogers, Lambon Ralph, Hodges & Patterson, 2004b).

Table 3 - Dissociations between performance on Pyramids and Palm Trees and object decision task conditions.

	JD					NJ			
	2008	2009	2010	2011	2012	Late 2007	Late 2008	Early 2009	Late 2009
High familiarity R > NR	-	C**	C**	S***	S***	C***	C***	S***	S***
High familiarity NR > R	-	C***	C***	C***	C***	C***	S*	S***	S***
Low familiarity R > NR	-	C***	C***	C***	C***	C***	C***	C***	S***
Low familiarity NR > R	-	C***	C***	C***	S***	C***	C***	C***	S***

Note: C = classical dissociation, S = strong dissociation. In all cases, a classical dissociation was observed when semantic performance was impaired and object decision performance was not. Strong dissociations always indicated a greater deficit in semantics that object decision. * $p < .05$, ** $p < .01$, *** $p < .001$, p values indicate the likelihood of a member of the control population exhibiting a greater discrepancy between test scores than the patient.

Figure captions

Figure 1 - Accuracy for each case in each test session, alongside the pattern reported by Rogers et al (2004).