COGNITIVE NEUROPSYCHOLOGY, 2006, 23 (4), 541–562

Psychology Press
Taylor & Francis Group

Semantic categorisation of novel objects in frontotemporal dementia

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Impaired semantic memory is ubiquitous in frontotemporal dementia (FTD), including patients with semantic dementia (SD), progressive nonfluent aphasia (PNFA) and nonaphasic FTD patients with a deficit in executive and social functioning (EXEC/SOC). One hypothesis attributes this to the degradation of specific categories of knowledge in semantic memory. This study explores the alternate hypothesis that impaired semantic memory in FTD can also reflect limitations in the categorisation processes that determine object meaning. Patients were taught a novel semantic category under two conditions: rule-based categorisation, where executive resources support the evaluation of specific features to determine category membership; and similarity-based categorisation, where category membership is determined by the overall resemblance of an item to a prototype or recalled exemplars. In the first experiment, patients learned a novel category composed of highly salient features. For SD patients, we found category membership judgment profiles following rule-based and similarity-based training that resembled the performance of control subjects. Categorisation was impaired following rule-based training in PNFA and EXEC/SOC patients. In the second experiment, we modified the category so that membership was determined by less salient features, thus increasing the burden on executive resources. Under these circumstances, SD patients' categorisation profiles continued to resemble those of control subjects, PNFA patients' category judgments were governed by feature salience, and EXEC/SOC patients' judgments were limited by impaired executive resources. These observations suggest that the semantic memory deficit in SD largely reflects degraded feature knowledge for familiar objects, while impaired semantic memory in PNFA and in EXEC/SOC patients largely reflects a deficit in the processes associated with semantic categorisation.

Frontotemporal dementia (FTD) is a neurodegenerative condition associated with progressive aphasia or a disorder of executive and social functioning (Grossman, 2002; McKhann, Trojanowski, Grossman, Miller, Dickson, & Albert, 2001; Neary et al., 1998). Although the disease is relatively rare within the general population, it is as common as Alzheimer's

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Portions of this work were presented at the Fourth International Meeting of Frontotemporal Dementia in Lund, Sweden, April 2003.
This work was supported in part by the US Public Health Service (AG17586, AG15116, and NS35867).

http://www.psypress.com/cogneuropsychology
DOI:10.1080/02643290542000094

disease within the sixth and seventh decade, the age range at which it is most often diagnosed (Knopman, Petersen, Edland, Cha, & Rocca, 2004; Ratnavalli, Brayne, Dawson, & Hodges, 2002). Progressive aphasia has several forms: Semantic dementia (SD), which is a fluent form, is characterised by profound naming difficulty (Hodges, Patterson, Oxbury, & Funnell, 1992; Moore, Dennis, & Grossman, 2005, Snowden, Goulding, & Neary, 1989; Warrington, 1975), word-finding pauses, and circumlocutory speech. This condition progresses to include a profound deficit in semantic memory, where the meaning of individual words becomes compromised (Hodges, Graham, & Patterson, 1995; Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001). Patients with progressive nonfluent aphasia (PNFA) have effortful speech that may be agrammatic or dysarthric, often associated with grammatical comprehension difficulty (Grossman et al., 1996; Snowden, Neary, Mann, Goulding, & Testa, 1992; Thompson, Ballard, Tait, Weintraub, & Mesulam, 1997). This may be due in part to the omission of verbs from their speech, and their difficulty in understanding verbs (Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001; Rhee, Moore, & Grossman, 2001; Thompson et al., 1997). Nonaphasic patients with FTD display a pattern of executive difficulty associated with a disorder of social comportment (EXEC/SOC) (Lough, Gregory, & Hodges, 2001; B. L. Miller, Darby, Benson, Cummings, & Miller, 1997; Rankin, Kramer, Mychack, & Miller, 2003; Snowden, Bathgate, Varma, Blackshaw, Gibbons, & Neary, 2001). This interferes with their interactions in social settings and their interpretation of the intentions of others (Gregory et al., 2002).

Deficits in FTD have been attributed in part to category-specific semantic memory impairment. For example, a sentinel feature of semantic memory difficulty in SD is said to be a deficit for objects such as natural kinds (Barbarotto, Capitani, Spinnler, & Trivelli, 1995; Basso, Capitani, & Laiacona, 1988; Breedin, Saffran, & Coslett, 1995; Warrington, 1975). The semantic deficit in PNFA is often shown to involve the meanings of verbs and their associated actions (Bak et al., 2001; Grossman et al., 1996; Rhee et al., 2001). Knowledge of social comportment may be degraded in EXEC/SOC patients, that is, they may show a category-specific deficit for social knowledge (Wood & Grafman, 2003). Hypotheses forwarded to explain such deficits have focused on the degradation of knowledge represented in semantic memory.

Our view of semantic memory includes at least two components: knowledge about objects, actions, and the like, such as general appearance and constituent features; and processes that use this knowledge to make semantic decisions (Grossman et al., 2002, 2003a; Grossman, Smith, Koenig, Glosser, Rhee, & Dennis, 2003b; Koenig et al., 2005). These processes include categorisation, which supports basic semantic functions such as grouping like objects and learning about new objects based on experience with known ones. In this report, we examine an alternate account of the semantic memory deficits in FTD—that impairment in the categorisation processes important for understanding concepts also plays a role.

There is much evidence to support the claim that SD patients' deficits reflect semantic memory impairment, rather than a modality-specific perceptual deficit or lexical access difficulty. For example, a semantic deficit is evident regardless of the modality or material used to represent a concept. Knowledge mediated by auditory stimuli such as the jingling of keys (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Hodges, Bozeat, Lambon Ralph, Patterson, & Spatt, 2000; Lambon Ralph, Graham, Patterson, & Hodges, 1999) and actions such as turning a key in a lock (Bozeat, Lambon Ralph, Patterson, & Hodges, 2002; Hodges et al., 2000) thus are as compromised as the visually mediated knowledge of a key's appearance. Since domains like abstract concepts (Breedin et al., 1995; Warrington, 1975) and number knowledge (Cappelletti, Butterworth, & Kopelman, 2001; Halpern et al., 2004) are relatively preserved in SD, patients' semantic difficulty has been attributed to the degradation of knowledge critical to the mental representation of a specific semantic category. However, several problems with the "degraded semantic knowledge" hypothesis have been raised. For example, the coherence of large semantic categories such as natural kinds has been questioned (Caramazza & Shelton, 1998). These controversies have concerned the scope and nature of the requisite knowledge, and hence the processes by which knowledge may be integrated have been largely unaddressed.

At least two kinds of categorisation processes contribute to semantic memory. One process involves a global comparison of a test object with a mental prototype representing category members (Rosch & Mervis, 1975; Smith & Medin, 1981) or with remembered instances of the semantic category (Medin, Goldstone, & Gentner, 1993; Medin & Schaffer, 1978). This "similarity-based" semantic process is relatively rapid, and appears to depend in large part on perceptual information. A second kind of categorisation process involves a more analytic or "rule-based" approach, where an object is evaluated with reference to a set of critical features (Allen & Brooks, 1991; Grossman et al., 2003b; Patalano, Smith, Jonides, & Koeppe, 2001; Rips, 1989; Smith & Sloman, 1994). This rule-based process has significant executive resource demands: selective attention governs inspection of the object for the relevant features; inhibitory control manages irrelevant features even if they are highly salient; switching attention allows exploration of the many features associated with an object; and the set of critical features must be kept active in working memory where they are up-dated to keep track of the results of the rule-based process. It is not difficult to conceive of specific situations where either a similarity-based or a rule-based approach to semantic categorisation may be most useful, and several investigators have shown that both approaches are available to healthy adults depending on the demands of a particular situation (Allen & Brooks, 1991; Grossman et al., 2003b; Hampton, 1998; Koenig et al., 2005; Patalano et al., 2001; Rips, 1989; Smith & Sloman, 1994).

One previous study examining semantic categorisation in FTD showed that patients are impaired at using rule-based processes to categorise known objects (Grossman et al., 2003b). In this report, patients were asked to categorise a sparsely described object (e.g., "a round object three inches in diameter") into one of two familiar categories (e.g., PIZZA or QUARTER). One of the categories (QUARTER) was fixed on the relevant dimension while the other (PIZZA) was variable. The quantitative amount in each description fell between the requisite size of the fixed-dimension category and the typical size of the variable category. The judgment task was presented under one of two conditions: a rule-based condition, in which subjects were told that the object must belong to only one of the categories; and a similarity-based condition, in which subjects were asked to judge which category the object most closely resembles. Healthy adults were able to modify their categorisation decisions based on the instructions, but FTD patients were unable to use the rule-based instructions to guide selecting the single category that meets the specified criterion in the description. This was true of members of each FTD subgroup, including SD, PNFA, and EXEC/SOC patients.

This finding appeared to suggest that rule-based semantic categorisation is compromised in FTD. However, the use of familiar concepts left open the possibility that some of these patients had degraded knowledge of features (e.g., the size of a quarter), and hence categorisation processes that could otherwise be applied to intact knowledge about objects could not be supported. In the present study, we separated object knowledge from categorisation processes by studying the acquisition of a novel concept; hence, degradation of knowledge previously represented in semantic memory cannot play a role. SD patients can relearn known objects (Graham, Patterson, Pratt, & Hodges, 1999), so we conjectured that they can learn about novel concepts and thus potentially demonstrate normal semantic categorisation. This would be consistent with the view that their impaired semantic memory is due largely to the degradation of feature knowledge previously represented in semantic memory. By comparison, if executive resources are limited in PNFA and EXEC/SOC patients (Boone, Miller, Lee, Berman, Sherman, & Stuss, 1999; Hodges & Patterson, 1996; Hodges et al., 1999; Lough et al., 2001; Pachana, Boone, Miller, Cummings, & Berman, 1996; Razani, Boone, Miller, Lee, & Sherman, 2001; Rhee et al., 2001), then such patients may have difficulty learning about a new object. This may be most evident for rule-based categorisation, which is so dependent on executive resources.

We taught subjects to categorise naturalistic novel animals by rule-based and similarity-based processes. The stimuli were intended to capture some of the characteristics of meaningful categories, while still being unfamiliar and thus requiring learning. The novel animals contained features of varying relative salience. In Experiment 1, we used a category based on the most salient features. In Experiment 2, we used a category that incorporated less salient features, which required that subjects disregard some salient features when categorising exemplars. We were thus able to manipulate the relative degree of executive resources involved in learning to categorise our novel stimuli in two ways: by the categorisation process employed, and by the nature of the category's feature-based structure. In this way, we sought to examine the separable contributions of process and content in semantic categorisation.

EXPERIMENT 1

Methods

Subjects

We studied 15 patients with FTD and 20 age- and education-matched healthy elderly controls. Most patients participated in both experimental conditions (described below) in counter-balanced order at least 6 weeks apart in order to avoid carry-over effects from the first exposure. Some patients could not participate in more than one condition because of personal circumstances such as illness or moving away from the area. Control subjects participated in one condition only. The patients were mildly or moderately demented according to the Mini-Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975). Hence, the patients' level of impairment was not severe enough to prevent the aphasic patients from understanding task instructions, or to prevent the patients with impaired executive resources from following them. Truly equating the dementia level of patients with different cognitive deficits, particularly when some patients' deficits are primarily linguistic and others are not, may not be possible. However, although there are limitations to the informativeness of the MMSE in assessing patients with frontal damage, we wished to equalise our patient groups on a standardised test. Hence, the patient subgroups were matched on their MMSE scores.

All subjects were right-handed native speakers of English. FTD patients were diagnosed according to published criteria (McKhann et al., 2001; The Lund and Manchester Groups, 1994). We excluded patients with other causes of dementia such as Alzheimer's disease, vascular disease or hydrocephalus, primary psychiatric disorders such as depression or psychosis, medical illnesses or metabolic conditions that may have resulted in encephalopathy, infectious diseases that may have resulted in progressive intellectual decline, and/or other medical conditions that may have an impact on cognitive performance. None of the subjects were taking sedating medications at the time of testing, although many patients were taking acetylcholinesterase inhibitors (e.g., donepezil) and a low dose of a serotonin-specific reuptake inhibitor antidepressant (e.g., sertraline), and some patients were taking a low dose of a non-sedating atypical neuroleptic (e.g., quetiapine).

We used a consensus mechanism to establish subgroup diagnosis, based on a review of a semi-structured history, detailed mental status exam, and complete neurologic exam by at least two independent, trained, reviewers. The subgroups were based on published criteria (Neary et al., 1998) that have been modified to improve reliability (Davis, Price, Moore, Campea, & Grossman, 2001;

Price, Davis, Moore, Campea, & Grossman, 2001). If the reviewers disagreed in their diagnosis (11% of cases), consensus was established through discussion.

One aphasic subgroup consisted of patients presenting with fluent progressive aphasia, also known as semantic dementia (SD, $n = 6$). Briefly, this is characterised by fluent and circumlocutory spontaneous speech that may be empty in content and is associated with impaired naming. None of the participating patients exhibited visual impairment, which characterises a variant of SD: The patients performed normally on the visual aspects of clinical assessments, such as copying geometric figures and judging line orientation. Four patients participated in both conditions, and one additional patient participated in each condition. Another progressive aphasic subgroup of FTD patients consisted of those presenting with progressive nonfluent aphasia (PNFA, $n = 5$). These patients have effortful speech that may be associated with dysarthria, agrammatism, and impaired grammatical comprehension. Four of these patients participated in both conditions, and a fifth patient participated only in the similarity condition. The nonaphasic subgroup of FTD patients presented with social and behavioural difficulties and limited executive functioning in day-to-day activities (EXEC/SOC, $n = 6$). Five of these patients participated in both conditions, and one patient participated only in the rule condition. These patients and their legal representatives participated in an informed consent procedure approved by the Institutional Review Board at the University of Pennsylvania. Demographic information and disease severity (MMSE scores) are provided in Table 1. The distribution of patient participation is summarized in Table 2.

Table 1 also includes performance on executive functioning. FTD patients were assessed with Trails B, a measure that requires selective attention, inhibitory control, and switching. Patients are asked to draw a line that alternates between ascending series of printed letters and numbers randomly distributed on a sheet of paper. They were given up to 300 s to complete this task. One PNFA patient and one SD patient could not perform the task. It can be seen that PNFA and EXEC/SOC patients required the most time to complete this measure, and made the largest number of errors during their performance.

Table 1. *Mean (± SD) demographic features, and performance on semantic and executive measures, in control subjects and subgroups of patients with frontotemporal dementia*

	Experiment 1							*Experiment 2*			
						Trails errors					
	Age	*Educ*	*Dura*	*MMSE*	*Trails time*	*Mean*	*Comp*	*Age*	*Educ*	*Dura*	*MMSE*
Control	68.2 (5.7)	15.0 (2.6)	–	–	107.1 (38.7)	0.38	25.0	71.8 (7.9)	14.3 (2.0)	–	–
Semantic dementia	57.0 (6.2)	15.8 (3.8)	42.4 (14.3)	25.6 (2.3)	219.5 (99.5)	0.80	18.0	64.1 (6.9)	15.3 (3.0)	45.0 (16.8)	23.7 (4.4)
Progressive nonfluent aphasia	76.5 (2.1)	14.0 (2.3)	36.5 (15.1)	25.8 (3.4)	245.4 (73.5)	0.83	15.9	76.9 (4.4)	14.3 (2.1)	57.0 (24.0)	24.6 (7.1)
Nonaphasic EXEC/SOC	66.5 (10.6)	14.8 (3.3)	40.5 (5.8)	22.8 (4.3)	252.5 (65.9)	1.17	19.8	70.8 (9.1)	14.4 (2.2)	57.6 (17.2)	23.2 (5.8)

Age = age in years; Educ = education in years; Dura = disease duration from reported onset in months; MMSE = Mini Mental State Exam (maximum score = 30); Trails time = seconds needed to complete Trails B Test (maximum = 300 s); Trails errors = mean number of errors, number of items completed (maximum 25).

Table 2. *Distribution of patient participation*

FTD patient subgroups	*Exp. 1*		*Exp. 2*	
	Rule	*Similarity*	*Rule*	*Similarity*
Semantic dementia	MO	MO	DO	DO
	DO	DO	DN	DN
	PR	PR	ES	ES
	VR	VR	ET	ET
	ET	LN	LN	LN
			PR	
			SK	
Progressive nonfluent aphasia	AY	AY	MR	MR
	SN	SN	SS	SS
	ME	ME	WN	WN
	RW	RW	WS	WS
		PA		WR
				ME
				RW
Nonaphasic EXEC/SOC	KZ	KZ	KZ	KZ
	AS	AS	FS	FS
	FL	FL	MN	MN
	NE	NE	SR	SR
	TG	TG	SE	SE
	MN	MN	HS	TG

The two experimental conditions, rule and similarity, are described below.

Materials

Stimuli were a set of realistic pictures of 64 biologically plausible novel animals comprising all possible combinations of six dichotomous features, e.g., short or long snout. The stimuli were intended to be characteristic of "natural" categories, that is, items that people would spontaneously group together as representatives of a kind. We assumed that subjects would be influenced by their past experience in classifying objects in general and animals in particular, but that the novelty of our stimuli would require learning specific to our categories. Relative feature salience was obtained from healthy subjects through an assessment procedure involving similarity judgments of all possible paired combinations of animals: We performed separate multidimensional scaling analyses of the similarity judgment scores for one through six dimensions. The results for the one-dimension analysis clustered the items by snout type; the two-dimension analysis clustered the items by snout type in one dimension and by leg type in the second dimension, and so on. We were thus able to obtain a rank ordering of feature salience since additional cluster-causing features emerged with each added dimension in the sequence of analyses. We used the four most salient features (i.e., legs, snout, colour, and neck) as "contributing" features in our novel category. A prototype animal was chosen at random. We defined category *members* as those animals that matched the prototype in at least three of the four contributing features. Thus, a *member* might have the same type of legs, snout, and colour as the prototype, but a different type of neck. There were 20 such items (including the prototype itself). The 24 *low distortion* items matched the prototype in two of the contributing features, such as the same type of legs and snout but a different colour and neck type. These items were nonmembers in the rule condition (described below) because they violated membership rules. However, they had equivocal membership status in the similarity condition (described below) because they bore equal resemblance to designated members and nonmembers seen during training. The 20 *high distortion* items matched no more than one of the prototype's contributing features, such as the same type of legs but different snout, colour, and neck types. These items were nonmembers in both the rule and similarity conditions (described below); they violated membership rules, and they most strongly resembled designated nonmembers seen during training. The two least salient features (i.e., teeth and tail) served as "distractor" features that were irrelevant to category membership. They were evenly and equally represented within each of the three stimulus types.

Training items were 40 unique *member/high distortion* pairs created from recombinations of eight members and eight high distortion items. We used only high distortion items as nonmember training examples, rather than including low distortion items, on the assumption that equivocal examples would make training more difficult. The training members closely resembled the prototype while still providing a wide range of acceptable instances of feature mismatches, and, analogously, the high distortion items strongly differed from the prototype while providing a wide range of feature matches. Thus, all training members had three (i.e., not all four) contributing features and either one or both of the two distractor features in common with the prototype; all training high distortion items had one (i.e., rather than no) contributing feature and one or none of the two distractor features in common with the prototype. Particular features were equally represented: Hence, a long snout, upright neck, short legs, and yellow colour (i.e., contributing features that matched the prototype) were each present in six of the eight training members, and a short snout, low neck, long legs, and red colour (i.e., contributing features that contrasted with the prototype) were each present in six of the eight training high distortion items. The 40 pairs were presented in a sequence in which each member and each high distortion training item appeared five times, and in which particular combinations of contributing features and distractor features were equally represented and distributed: Within every sequence of eight pairs, each member and each high distortion item appeared once. The order was random within each eight-pair sequence, with the stipulation that particular combinations of features were equally distributed among the first four and last four pairs. Our intention was to expose subjects to a representative range of members and high distortion nonmembers, with no closely spaced repetition of particular combinations of features and no discernable pattern of presentation. This was to ensure that training would not impose particular feature biases or anticipation of particular items. In addition, the distribution of feature configurations made it highly unlikely that subjects could appear to demonstrate learning by adopting a simplified strategy such as attending to a single feature. We presented these member/high distortion pairs by computer in each of two training conditions, described below.

Procedure

Rule training procedure. Subjects were initially shown a card containing outline drawings and written descriptions of the four contributing features (e.g., the words "long snout" captioning an outline of a long snout). They were told that an animal called a "crutter" had to have at least three of the four described features. They were then told that they would see pairs of animals on the computer screen, one of which would be a crutter and one of which would not, along with the same descriptions and outlines of features. Their task was to decide which animal in each pair was a crutter, based on the "at-least-three-of-four-features" rule. Subjects were then shown a card picturing the captioned outlines and a sample member/high distortion pair, in the same configuration as these images would appear on the computer screen, to familiarise them with the screen appearance and procedure before training and data collection began. The training session followed. A sequence of images was presented consisting of a member/high distortion pair arrayed horizontally in the lower half of the computer screen and the feature descriptions and outline drawings in the upper half. Hence, although the rules could be described verbally, the requisite individual requisite features were presented visually as well. Figure 1(a) shows a sample image. Subjects had up to 15 seconds to respond, and the experimenter provided feedback (i.e., correct or incorrect) after the response. Responses were indicated by key press, corresponding spatially to the screen location (left or right) of the chosen item. The members and high distortion items were equally distributed in the left and right positions. If a subject chose correctly for 7 out of 8 consecutive pairs after exposure to the first 8 pairs, then training ended; otherwise, all 40 pairs were shown. Thus, all subjects saw at least the first 16 pairs, i.e., were exposed to each member and each high distortion training item minimally twice. Responses were recorded. Failure to respond to a pair in 15 seconds was counted as an error for purposes of determining when to end the training session and for our error analyses.

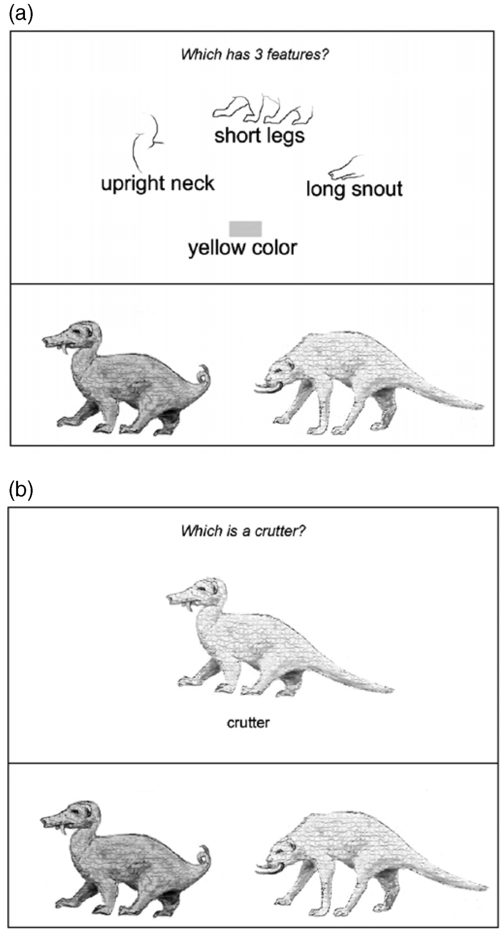

Figure 1. *Examples of training stimuli (a) Rule-based training (b) Similarity-based training.*

Similarity training procedure. Subjects were initially shown a card picturing and naming the prototype, and they were told it was an animal called a "crutter." They were then told that they would see that same crutter along with pairs of animals on the computer screen, one of which would also be a crutter and one of which would not. Their task was to decide which animal in the pair was a crutter, based on overall similarity to the example crutter. Subjects were then shown a card picturing the prototype that was labelled "crutter" and a sample member/high distortion pair to familiarise them with the screen appearance and procedure before training and data collection began. The training session followed. A sequence of images was presented consisting of the labelled prototype in the upper half of the computer screen and the same horizontally arrayed member/high distortion pairs as in the rule training procedure in the lower half. Figure 1(b) shows a sample image. All other aspects (e.g., timing, mode of response, feedback, and data collection) were the same as in the rule training session. Figure 1 shows that verbal and visual information were present in both training conditions. Training data for two control subjects were not automatically recorded due to computer error; the accuracy of their responses was ascertained from the experimenter's written records made during the training session, and these responses were included in the analyses.

Testing procedure. Testing followed training after about 1 minute, and presentation was identical across both training conditions. Subjects saw a sequential presentation of the entire set of 64 animals in a fixed random order, and judged whether each was a crutter. Subjects indicated their choice by pressing a labelled computer key (a right-hand key for "yes" and a left-hand key for "no"). No feedback was provided. Subjects had up to 15 seconds to respond. Analyses included only trials to which subjects responded. Subjects in the rule condition were provided with a card showing the captioned feature outlines to prompt them to use the "three-of-four-features" rule for identifying a crutter, and subjects in the similarity condition were provided with a card picturing and naming the prototype to prompt them to base their judgments on the overall appearance of a crutter. These prompt cards were intended to ensure that difficulties in categorisation could not simply be attributed to subjects' inability to recall the requisite features or the appearance of the prototype. Previous work comparing populations with and without episodic memory impairment has shown that prompt cards such as this support performance without biasing previously acquired learning strategies (Oscar-Berman & Samuels, 1977).

Preliminary work with Alzheimer's disease patients using these materials without the use of prompt cards showed random performance following both training conditions. Preliminary work in FTD without the use of prompt cards showed patterns of categorisation similar to those described below. We elected to use the prompt cards to minimise the potential confounds associated with potentially unequal episodic memory performance across FTD subgroups.

Results and discussion: Experiment 1

Training

We calculated the number of training trials subjects needed to reach our learning criteria; these are summarised in Table 3. The results suggest that controls, SD patients, and PNFA patients each learned to categorise our novel stimuli across training conditions with equal efficiency. EXEC/SOC patients required more trials for rule-based training relative to similarity-based training, but this difference did not reach significance, $t(4) = 1.14$, *ns*. The results also revealed that PNFA patients required more training trials overall than did other subject groups. A repeated-measures analysis of variance (ANOVA), with a Group (4—control, SD, PNFA, and EXEC/SOC) × Training Condition (2—rule-based, similarity-based) design showed a marginal main effect for group, $F(3, 20) = 2.76$, $p = .07$, but no main effect of training condition, $F(1, 20) = 0.00$, *ns*, nor a Group × Condition interaction effect, $F(3, 20) = 0.65$, *ns*. Post hoc tests (Tukey HSD) confirmed that the PNFA patients required marginally more training trials overall than controls, $p = .07$.

Table 3. *Mean (± SD) number of trials[a] prior to reaching criterion for category acquisition*

	Exp. 1 (concordant category)		*Exp. 2 (discordant category)*	
Subject groups	*Rule*	*Similarity*	*Rule*	*Similarity*
Control	16.0 (0.0)	17.6 (2.5)	16.5 (1.6)	21.3 (6.5)
Semantic dementia	17.4 (2.3)	16.6 (0.9)	21.4 (8.6)	19.0 (5.6)
Progressive nonfluent aphasia	22.5 (11.0)	24.8 (7.4)	18.3 (3.2)	26.3 (9.8)
Nonaphasic EXEC/SOC	24.5 (12.0)	18.8 (3.6)	24.8 (11.9)	29.2 (10.1)

[a]Sixteen trials received by everyone as a minimum exposure.

Category judgments at test

We calculated the proportion of items endorsed as members for each stimulus type. Hence, successful categorisation in either condition would require higher endorsement scores for members than for high distortion items. The critical distinction between rule-based and similarity-based categorisation lies in the low distortion scores: rule-based categorisation should yield a high endorsement score for members, and equally low scores for low distortion and high distortion items, since both these latter item types qualify as nonmembers according to the rules. This judgment profile would capture the sharp category boundary characteristic of rule-based categorisation. In contrast, similarity-based categorisation should yield a high score for members, an intermediate score for low distortion items, and a low score for high distortion items. This judgment profile would capture the graded character of similarity-based categorisation, in which membership reflects degree of resemblance to the prototype. Hence, we accepted a judgment profile as indicative of rule-based categorisation if the score for members was significantly greater than the score for low distortion items and the scores for low distortion and high distortion items were not significantly different from each other. (In reporting individual patient data, we refer to performance as "rule-like" if the difference between scores for members and low distortion items is greater than the difference between scores for low distortion and high distortion items.) We accepted judgment patterns as indicative of similarity-based categorisation if the score for members was significantly greater than the score for low distortion items, which in turn was greater than the score for high distortion items. (It is possible to have a "similarity-like" pattern with a sufficiently flat slope such that member scores are significantly higher than high distortion scores, while low distortion scores, although falling midway, do not significantly differ from either endpoint. We consider this a “weak” form of similarity-based categorisation.)

We first analysed overall performance, using a repeated-measures ANOVA, with a Group (4—controls, SD, PNFA, EXEC/SOC) × Training Condition (2—rule-based, similarity-based) × Membership status (3—member, low distortion, high distortion) design. The findings are summarised in Figure 2. Subjects generally profited from training, as seen by highest scores for members and lowest scores for high distortion items. This observation was confirmed by a main effect for membership status, $F(2, 42) = 201.01$, $p < .001$, with differences between all three stimulus types reaching significance at the $p < .01$ level, according to t-tests. Subjects also performed differently across conditions. This observation was confirmed by a main effect for training condition, $F(1, 21) = 5.64$, $p < .05$. Finally, and most importantly, different FTD subgroups performed differently from each other, depending on the training condition. This was confirmed by interactions for Group × Membership Status, $F(6, 42) = 2.60$, $p < .05$, and for Group × Training Condition × Membership Status, $F(6, 42) = 2.91$, $p < .05$.

We examine these interaction effects below by considering the performance profile of each group following each training condition.

Control subjects. Control subjects showed characteristically different patterns of performance

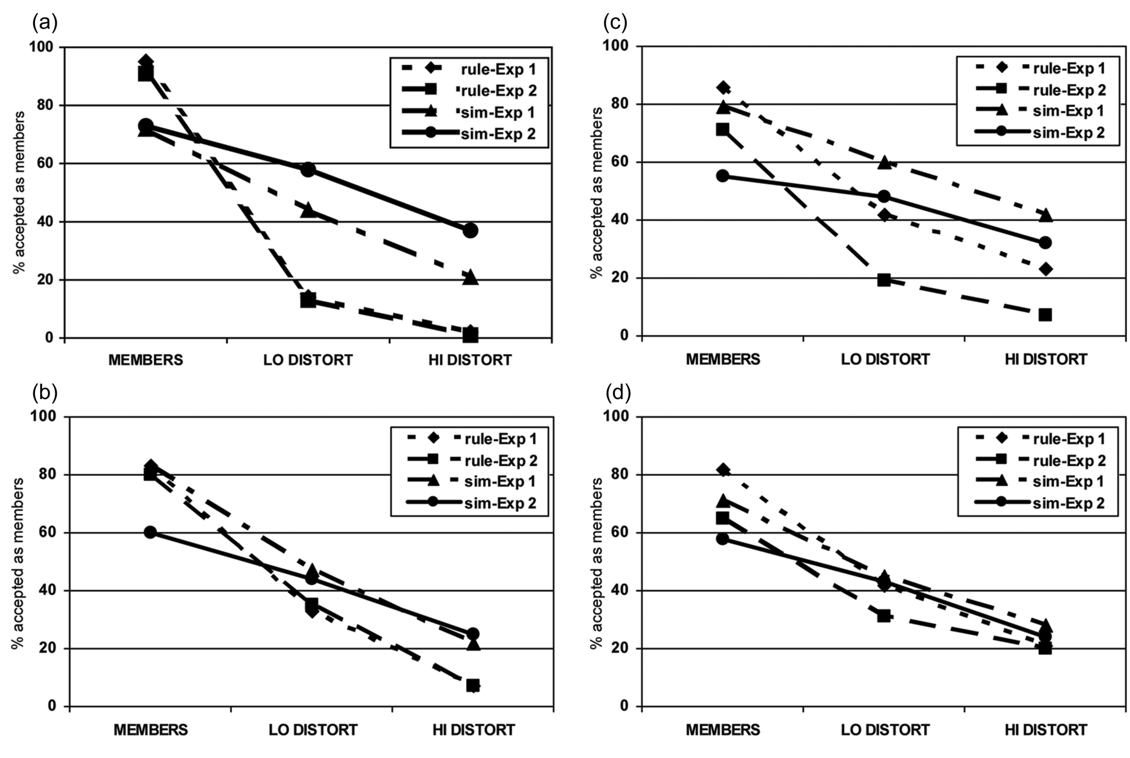

Figure 2. *Patterns of category membership judgment following rule-based and similarity-based training during judgments of categories composed of more salient and less salient features. (a) Control subjects; (b) Semantic dementia patients; (c) Progressive nonfluent aphasia patients; (d) EXEC/SOC patients.*

depending on the preceding training condition. Their performance is summarised in Figure 2(a). Following rule-based training, control subjects were very accurate in their membership judgments, with a clearly delineated category boundary. Thus, they sharply distinguished between members of the category and nonmembers, including both low distortion stimuli, $t(9) = 14.39$, $p < .001$, and high distortion stimuli, $t(9) = 43.57$, $p < .001$. Moreover, their judgments for low distortion and high distortion stimuli did not differ.

Control subjects showed a graded profile membership endorsement following similarity-based training. Members were more likely to be accepted as exemplars of the category than low distortion stimuli, which in turn were more likely to be accepted than high distortion stimuli (all contrasts significant at least at the $p < .05$ level, according to t-tests). Control subjects were less likely to endorse low distortion items under the rule-based condition than under the similarity-based condition, $t(9) = 6.03$, $p < .001$, emphasising the distinction between the graded nature of similarity-based categorisation compared to the abruptly bounded nature of rule-based categorisation. Without specific rule-like criteria to guide semantic categorisation judgments, moreover, control subjects were less likely to accept members, $t(9) = 5.26$, $p < .001$, or to reject high distortion stimuli as nonmembers, $t(9) = 3.25$, $p < .01$, in their semantic categorisation judgments following similarity-based training compared to rule-based training.

Semantic dementia patients. SD patients met our criteria for distinct rule-based and similarity-based categorisation profiles, although to a lesser extent than controls. SD patients' performance is summarised in Figure 2(b). Following rule-based training, SD patients thus were relatively accurate at accepting members and rejecting high distortion stimuli, differing statistically in their acceptance of these stimuli as category exemplars, $t(4) = 9.56$, $p < .001$. Critically, judgments of members and low distortion stimuli differed, $t(4) = 6.08$, $p < .005$, while low distortion and high distortion stimuli were judged in a statistically equivalent manner. Inspection of individual patient performance profiles revealed rule-like judgments in 4 (80%) out of 5 SD patients. SD patients were less accurate in accepting members as exemplars of the category than were control subjects, $t(15) = 2.28$, $p < .05$. SD patients thus showed some ability to use the critical features contributing to a new concept for the purpose of discriminating between members and nonmembers based on a rule, although they were not able to profit from the specific feature criteria as much as control subjects in their judgments of members.

SD patients showed a graded judgment profile following similarity-based training. Thus, they were more likely to accept a member as an exemplar of the category than a low distortion stimulus, and were more likely to accept a low distortion stimulus than a high distortion stimulus as a category exemplar (all contrasts significant at least at the $p < .05$ level, according to t-tests). This graded pattern of categorisation was seen in 4 (80%) of the 5 SD patients. Like controls, SD patients were more likely to correctly judge a high distortion stimulus to be a nonmember under the rule-based condition than the similarity-based condition, $t(4) = 2.75$, $p < .05$, emphasising that they can take some advantage of the criteria that specify category membership. However, SD patients did not differ in the likelihood with which they accepted a member following rule-based and similarity-based training, $t(4) = 0.07$, *ns*, again suggesting that they were not as effortless as control subjects at using specific semantic criteria under the rule-based condition to identify a category member.

Progressive nonfluent aphasic patients. PNFA patients are summarised in Figure 2(c). Their judgments were consistent with similarity-based processing following both training conditions. Although it appears as if this patient group, like SD patients, demonstrated different performance following rule-based and similarity-based training, the apparent distinctions were not statistically robust. Following rule-based training, these patients were relatively accurate in their categorisation of members and high distortion stimuli, and they distinguished statistically between these categories of stimuli, $t(3) = 3.43$, $p < .04$. However, their endorsements of members and low distortion stimuli did not differ significantly, $t(3) = 2.07$, *ns*. Inspection of individual patient profiles showed that only 1 (25%) out of 4 PNFA patients demonstrated a rule-like categorical performance profile. PNFA patients were less accurate than control subjects at accepting members, $t(15) = 2.00$, $p < .07$, and at rejecting low distortion items, $t(12) = 2.42$, $p < .05$, following rule-based training. These findings suggest a rule-based processing impairment in PNFA.

PNFA patients showed graded judgments of category membership following similarity-based training. They distinguished between members and high distortion stimuli, $t(3) = 3.43$, $p < .05$, although only marginally between members and low distortion stimuli, $t(3) = 2.07$, *ns*, and between low distortion stimuli and high distortion stimuli, $t(3) = 2.06$, *ns*. Unlike control subjects, PNFA patients did not differ in their categorisation of low distortion stimuli following similarity-based training compared to rule-based training, $t(3) = 1.49$, *ns*, emphasising this patient group's minimal distinction between judgments following similarity-based and rule-based training. Moreover, following similarity-based training, PNFA patients were more accurate in judging members that had previously been seen during training compared with members seen for the first time at test, $t(6) = 4.48$, $p < .01$. Neither controls nor any of the other FTD subgroups showed any difference between judgments for old and new test stimuli. This suggests that, although PNFA patients retain some ability to categorise our novel stimuli by a similarity-based process, their judgments of members were based in part on their recognition of stimuli presented during training.

Patients with a disorder of executive and social functioning. EXEC/SOC patients, summarised in Figure 2(d), showed a graded pattern of membership acceptance following both rule-based training and similarity-based training, suggesting a deficit in rule-based semantic categorisation. Following rule-based training, these patients distinguished between members and low distortion items, $t(5) = 4.72$, $p < .01$. However, they also distinguished between low distortion and high distortion, $t(5) = 2.67$, $p < .05$. Inspection of individual patient profiles showed that only 1 (17%) out of 6 EXEC/SOC patients demonstrated a rule-like performance profile. Following rule-based training, EXEC/SOC patients were more likely to incorrectly endorse low distortion stimuli, $t(14) = 2.84$, $p < .05$, and were less likely to correctly endorse members, $t(14) = 2.54$, $p < .05$, than were control subjects, further emphasising their non-rule-like pattern of performance.

EXEC/SOC patients showed graded judgments of category membership following similarity-based training. Judgments differed for members relative to low distortion stimuli, and for low distortion stimuli relative to high distortion stimuli (each contrast significant at the $p < .05$ level, according to t-tests), suggesting preserved similarity-based processing. Unlike control subjects, EXEC/SOC patients did not differ in their categorisation of low distortion stimuli following similarity-based training compared to rule-based training, $t(5) = 0.33$, *ns*.

In sum, the results demonstrate that despite SD patients' hallmark semantic memory impairment, semantic categorisation by this patient group can be reasonably accurate when the judgments do not depend on the integrity of knowledge in long-term semantic memory. Furthermore, SD patients appear capable of employing two qualitatively distinct categorisation processes, comparable to the behaviour of normal control subjects. PNFA patients appear less able to employ rule-based categorisation. They also differ from controls in their similarity-based categorisation, as evidenced by the shallow slope of their performance profile, as well as their apparent reliance on recognition of training stimuli at test. SOC/EXEC patients show no tendency to employ rules following rule-based training, apparently relying on similarity-based processing regardless of how they have been trained.

EXPERIMENT 2

The previous experiment was designed such that one categorisation process was perceptually based and relatively automatic, while the other was more resource demanding. Category membership of items was determined by highly salient features for both processes. Hence, the resources needed to selectively attend to contributing features and inhibit noncontributing features were not especially taxed by the particular stimuli. However, comprehension in the real world often requires executive resources like selective attention and inhibitory control to override salient but nondiagnostic features. For example, bats are *mammals*, not *birds*, despite their bird-like wings. Bats can be correctly categorised by inhibiting salient features like *wings* and attending to less salient but diagnostic features like *fur*. In the following experiment, we sought to further test the role of executive resources such as these during semantic categorisation. Specifically, in Experiment 2 we based category membership on the features of the stimuli judged *least* salient, and included the most salient features as distractor features.

Our method of rule-based training focuses subjects on discrete contributing features. Since rule-based training does not expose subjects to a prototype during acquisition, subjects have no grounds for associating particular distractor features (i.e., those present in the prototype) with the category, and hence have little need to inhibit distractor features. However, pilot studies suggested that all six of the features are readily discernible, even though they do not contribute equally to perceived inter-item resemblance. We conjectured, therefore, that a categorisation process specifically isolating discrete features at the expense of the whole item would be relatively insensitive to feature salience—at least with our particular set of stimuli. Consequently, we expected little change in control subjects' categorisation performance as a function of reduced feature salience following rule-based training. Since SD patients have relatively preserved executive resources, we also expected little decrement in their rule-based performance. The extent of additional difficulty in FTD patients' rule-based performance with a category composed of less salient features should indicate the stability of their rule-based processing ability. In this context, the moderate resource limitations of PNFA patients could result in some performance decrement following rule-based training for a category composed of less salient features. SOC/EXEC patients were expected to show little additional impairment in their rule-based performance with a less salient category because their executive resource difficulty was extreme enough to have resulted in poor rule-based performance even with more salient features.

Similarity-based training involves exposure to the prototype, which displays both contributing and distractor features, at every trial. In the previous experiment, the highly salient *snout* served as a contributing feature, and the less salient *tail* served as a distractor feature. However, in our category composed of less salient features, the *snout* serves as a distractor feature irrelevant to category membership, while the less salient *tail* serves as a contributing feature. We have characterised similarity-based categorisation as a relatively automatic process. Learning a category composed of features that contribute most strongly to perceived inter-stimulus resemblance should require minimal resources beyond this automatic process. In contrast, learning the category composed of less salient features involves disregarding the prototype's snout length and attending to its tail shape. This requires resources such as inhibitory control and selective attention. Under these circumstances, we reasoned that similarity-based training for a category composed of less salient features would be sensitive to resource limitations. Control subjects were expected to demonstrate more difficulty learning the new category composed of less salient features than the salience-based category in Experiment 1 because of an age-related limitation in executive resources

(Dulaney & Rogers, 1994; Hartman & Hasher, 1991; Jonides, Marshuetz, Smith, Reuter-Lorenz, & Koeppe, 2000). Hence, while the category would be learnable, we expected reduced judgment accuracy at test. Unlike similarity-based training for a category composed of highly salient features, the extent of FTD patients' difficulties following similarity-based training for a category composed of less salient features should be sensitive to their executive resource limitations. Hence, we expected SD patients, like control subjects, to find the new category somewhat more difficult to learn and subsequently to judge. We expected PNFA and EXEC/SOC patients to experience greater difficulty with the less salient category under similarity-based conditions because of their resource limitations.

Methods

Subjects

Twenty-one FTD patients and 19 age- and education-matched healthy elderly controls participated in this experiment. As summarised in Table 1, the patients were mildly or moderately demented according to the MMSE. All subjects were right-handed native speakers of English. The diagnoses of the patients and their criteria for inclusion and exclusion were the same as in Experiment 1.

As in Experiment 1, there were two training conditions, rule-based and similarity-based, and patients participated in one or both conditions in a randomly determined, counterbalanced order, at least 1 month apart. Seven SD patients participated; five participated in both conditions, and two participated only in the similarity condition. Seven PNFA patients participated; four participated in both conditions, and three participated only in the similarity condition. Seven SOC/EXEC patients participated; five participated in both conditions, one participated only in the similarity condition, and one participated only in the rule condition. Seven patients had also participated in Experiment 1. The distribution of patient participation is indicated in Table 2. Control subjects participated in one randomly assigned condition. Data from one control subject in the similarity condition were excluded because the subject responded "yes" to all test items; hence, nine control subjects were included in each condition.

Materials

Stimuli in Experiment 2 were the same set of 64 novel animals used in Experiment 1, with the same animal serving as the prototype. As in Experiment 1, we defined members as those stimuli matching the prototype on at least three of four designated features, low distortion items as those stimuli matching the prototype on two of these features, and high distortion items as those stimuli matching the prototype on maximally one of the designated features. However, unlike Experiment 1, we used the four features identified by our feature assessment as being the least salient. Hence, the four features contributing to membership in Experiment 2 were *tooth, tail, neck*, and *colour*. Two of these features, *neck* and *colour*, were also contributing features in Experiment 1, while the remaining two, *tooth* and *tail*, had served as distractor features in Experiment 1 because of their low salience. *Snout* and *leg*, highly salient features that had contributed to category membership in Experiment 1, served as distractor features in Experiment 2. We will refer to the category used in Experiment 2 as *discordant*, and we will refer to the category used in Experiment 1 as *concordant*.

Procedure

Experiment 2 differed from Experiment 1 only in the particular stimuli designated as members, low distortion items, and high distortion items, reflecting the reassignment of particular stimulus features as contributing or distractor. Hence, there were separate rule and similarity training conditions followed by a single test procedure. Subjects in the rule training condition were shown captioned outlines of the four features that served as contributing features in Experiment 2, and were instructed as they had been in Experiment 1. Subjects in the similarity training condition were shown the identical labelled sample image (i.e., the prototype) seen by subjects in Experiment 1, and were asked to choose the member item in each training pair based on overall resemblance to the sample crutter.

The test session in Experiment 2 showed the identical sequence of all 64 items as in Experiment 1 except for the reordering of three of the items. Because of the re-designation of stimuli as members, low distortion, and high distortion items, reordering was necessary so that no more than three items of any one stimulus type would be presented sequentially.

Results and discussion

Discordant category training

As in Experiment 1, we calculated the number of training trials subjects needed to reach our training criteria. The results of training are summarised in Table 3. In contrast with Experiment 1, acquiring the discordant category by similarity-based training required more trials than by rule-based training for all subject groups except the SD patients. An ANOVA with a Group (4—control, PNFA, SD, EXEC/SOC) × Training Condition (2—Rule-based, similarity-based) revealed a significant main effect for training condition, $F(1, 26) = 6.70$, $p < .02$, and a Group × Training Condition interaction effect that approached significance, $F(3, 26) = 2.30$, $p < .10$. The greater trial requirement for similarity-based training was significant for control subjects, PNFA patients, and EXEC/SOC patients at $p < .05$.

Discordant category judgments at test

As in Experiment 1, we examined proportions of membership endorsement for each stimulus type, using the identical ANOVA analysis. As in Experiment 1, subjects endorsed member, low distortion, and high distortion items to different extents, $F(2, 52) = 197.89$, $p < .001$, and performance differed according to training condition, $F(1, 26) = 13.38$, $p < .001$. Each subject group showed a distinct endorsement pattern, differentiated further by training condition. These distinctions were confirmed by interactions for Group × Training Condition, $F(3, 26) = 3.17$, $p < .05$, Group × Membership Status, $F(6, 52) = 3.05$, $p < .05$, and Group × Training Condition × Membership Status, $F(6, 52) = 3.76$, $p < .005$. In comparing Experiments 1 and 2, we found that subject groups were differently affected by the change in feature salience. This observation was confirmed by an ANOVA that additionally incorporated category feature salience as a factor (2—concordant, discordant). There was a significant Group × Feature Salience interaction effect, $F(3, 26) = 4.42$, $p < .05$.

In sum, patients' performance differed depending on the training condition, as in Experiment 1, and also differed depending on the salience of the features contributing to the category.

Control subjects. Test results for control subjects for Experiment 2 closely resembled results for Experiment 1, as shown in Figure 2(a). Following rule-based training, control subjects' performance for the discordant essentially duplicated that for the concordant category. Judgments for each stimulus type thus were the same across Experiments 1 and 2 (all contrasts at the $p > .10$ level, according to t-tests).

Figure 2(a) shows graded category membership judgments following similarity-based training for the discordant category (each contrast significant at least at the $p < .05$ level, according to t-tests), but similarity-based judgments for the discordant category differed from similarity-based judgments for the concordant category in two ways: Control subjects more frequently endorsed members seen during training than members seen only at test, $t(9) = 4.03$, $p < .01$, suggesting a reliance on memory for training items. In addition, control subjects in Experiment 2 were less likely to reject nonmembers, that is, low distortion stimuli, $t(9) = 2.32$, $p < .05$, and high distortion stimuli, $t(9) = 2.40$, $p < .05$. The tendency to grant membership to nonmembers apparently resulted from endorsing those nonmembers sharing salient distractor features with the prototype, e.g., low or high distortion items with long snouts. Control subjects thus seemed to show some effects of the additional inhibitory control demands needed to learn the discordant category, consistent with the well-known limitations in inhibitory control associated with ageing (Dulaney & Rogers, 1994; Hartman & Hasher, 1991; Jonides et al., 2000). In sum, control subjects' judgments met with our expectations: (1) they maintained different judgment patterns reflecting qualitatively distinct categorisation processes for both the concordant and discordant categories; (2) they performed identically across Experiments 1 and 2 following rule-based training; and (3) they were less accurate in their judgment profiles following similarity-based training in Experiment 2 than in Experiment 1.

Semantic dementia patients. Figure 2(b) shows that SD patients' performance following rule-based training for the discordant category was essentially identical to their performance for the concordant category. This was confirmed by *t*-tests directly comparing judgments across concordant and discordant categories for each stimulus type (each comparison at the $p > .10$ level). A rule-like categorical profile of membership judgments was seen in 3 (60%) out of 5 SD patients. Hence, in keeping with their relatively spared rule-based processing ability, SD patients, like controls, maintained their level of rule-based performance in the face of reduced feature salience.

SD patients' judgments of the discordant category following similarity-based training were graded (each comparison significant at least at $p < .01$), with 6 (83%) out of 7 SD patients showed a graded categorisation profile. Performance was not identical to Experiment 1: While judgments of low distortion and high distortion stimuli did not differ across experiments, SD patients were less accurate at judging members of the discordant category than of the concordant category, $t(6) = 2.95$, $p < .05$. As with controls, this suggests some difficulty with less salient features, and this modest deficit does not appear to extend much beyond what might be expected as a function of the normal ageing process.

In sum, SD patients resembled controls in their response to the discordant category: they showed fairly distinct categorisation profiles following rule-based and similarity-based training; they maintained their level of rule-based processing; and their similarity-based processing was modestly affected by the reduced feature salience.

Progressive nonfluent aphasics. PNFA patients' judgments following rule-based training appeared to exhibit some rule-based processing, but as in Experiment 1, performance did not meet our criteria: PNFA patients differentiated between members and low distortion stimuli, $t(6) = 6.83$, $p < .01$, but they also differentiated between low distortion and high distortion stimuli, $t(6) = 4.61$, $p < .01$. Results are shown in Figure 2(c). Three (75%) out of 4 individual PNFA patients demonstrated a rule-like categorical judgment profile for the discordant category. Although judgments following rule-based training for the discordant and concordant categories form similar slopes, profiles were not equivalent: Discordant category endorsements following rule-based training were less frequent for each item type (all comparisons significant at least at the $p < .05$ level, according to *t*-tests). These results suggest that PNFA patients, unlike SD patients and controls, are influenced by feature salience on a task where salience should be irrelevant.

PNFA patients differed in their response profiles following similarity-based training across the discordant and concordant categories as well. They showed only weak similarity-based categorisation of the discordant category. Thus, they were more likely to accept a member as a category exemplar than a high distortion stimulus, $t(6) = 3.57$, $p < .05$, but *t*-tests did not show a difference between member and low distortion stimuli, nor between low distortion and high distortion stimuli. The poorly graded judgment pattern for the discordant category was seen in all of the PNFA patients. Indeed, 3 (42%) of the PNFA patients endorsed low distortion items more often than members. Moreover, their performance with members seen during training was more accurate than their performance with members seen only at test, $t(6) = 4.75$, $p < .01$. The shallowness of the slope, combined with greater accuracy for previously seen items, suggests that PNFA patients encountered difficulty inhibiting the salient features sufficiently to acquire the discordant category, and instead relied on recognition of items encountered during training.

In sum, unlike SD patients and control subjects, PNFA patients' membership judgments changed in the face of a category composed of less salient features following both rule-based training and similarity-based training. This is consistent with executive resource limitations, particularly with the inhibitory control needed to ignore the discordant category's highly salient distractor features.

EXEC/SOC patients. EXEC/SOC patients showed equivalent graded categorisation profiles for the discordant category following both rule-based training and similarity-based training, as shown in Figure 2(d). *T*-tests showed that their judgments of members, low distortion stimuli, and high distortion stimuli following similarity-based training did not differ from their judgments of these stimuli following rule-based training (all contrasts at the $p > .10$ level, according to t-tests). That is, categorisation judgments for the discordant category following rule-based training were no more rule-like than judgments following similarity-based training. SOC/EXEC patients were significantly less accurate at judging discordant members as category exemplars compared to members from the concordant category, $t(5) = 3.27$, $p < .05$, following rule-based training. They were also less accurate judging discordant category members than were control subjects, $t(14) = 3.95$, $p < .01$, and SD patients, $t(11) = 2.33$, $p < .05$.

GENERAL DISCUSSION

Our view of semantic memory involves two components: The representation of knowledge, and processes such as categorisation that use this knowledge to establish meaning. Our goal in this study was to separate the contributions of knowledge and processing components in semantic memory, enabling us to clarify the sources of impaired semantic memory in subgroups of patients with FTD.

Our examination of semantic categorisation processes applied to a meaningful novel category revealed an interesting paradox: SD patients are the FTD subgroup whose disease is marked by the greatest semantic memory impairment, yet they performed the most like healthy control subjects on a task involving the acquisition of a novel semantic concept. In contrast, EXEC/SOC and PNFA patients, who exhibit modest semantic deficits on widely used measures of semantic memory, performed relatively poorly. These findings emerged in our evaluation of rule-based and similarity-based semantic categorisation processes. The distinctions between these processes are manifested in characteristic category judgment profiles, that is, a sharply demarcated category boundary for rule-based categorisation reflecting the application of necessary and sufficient rules, and graded judgment for similarity-based categorisation reflecting the overall resemblance to a prototype. These two processes are also potentially distinguishable by their differing sensitivity to feature salience: rule-based processing focuses on specific features irrespective of their salience, while similarity-based processing is inherently wedded to perceptual salience. Our stimuli and manner of training were designed to enhance these differences in salience sensitivity. Hence, reduced salience of contributing features should minimally affect rule-based processing, while similarity-based processing is more challenging when the category is composed of less salient features.

The qualitative distinctions between the two categorisation processes were strongly apparent in the control subjects' judgment profiles. In addition, performance was virtually identical following rule-based training for both the concordant and discordant novel categories, while there were modest differences across categories following similarity-based training. This emphasises the relative resilience of rule-based processing to feature salience and reflects the sensitivity of similarity-based processing to reduced feature salience.

Semantic dementia patients' patterns of performance resembled those of healthy controls: This patient group exhibited relatively rule-like categorical performance following rule-based training for both the concordant and discordant categories. SD patients were less accurate in similarity-based judgments for the discordant category relative to the concordant category, again parallelling responses by controls. The two categorisation processes hence appear to be relatively preserved, and can be employed when object knowledge is provided. In contrast, as described previously, SD patients have shown impairment in their rule-based categorisation when asked to judge familiar objects (Grossman et al., 2003b). Although semantic impairment in SD has been attributed to the degradation of knowledge in semantic memory (Barbarotto et al., 1995; Basso et al., 1988; Bozeat et al., 2000, 2002; Hodges et al., 1992, 2000; Lambon Ralph et al., 1999; Moore et al., 2005; Snowden et al., 1989; Warrington, 1975), patients' reasonably normal categorisation profiles in the present study suggest that their deficits with familiar objects largely reflects degraded knowledge, rather than a processing impairment, at least in the relatively early stages of their disease.

Progressive nonfluent aphasia patients appeared to demonstrate some preserved use of rule-based categorisation. The modestly rule-like patterns seen for both the concordant and discordant category were not statistically reliable. However, the fact that PNFA patients demonstrated some ability to categorise the discordant category following rule-based training, despite their very poor similarity-based performance for that category, suggests that they were using a rule-like pattern with some success. The small number of PNFA patients and consequent statistical power issues preclude our claiming with assurance that this patient group has no ability to categorise by rules. However, PNFA patients are clearly impaired at rule-based categorisation, and in addition, appear to be unduly influenced by feature salience during rule-based categorisation, in contrast to SD patients and healthy controls. The relatively strong influence of feature salience is also apparent in similarity-based categorisation. PNFA patients seemed less able than SD patients and controls to inhibit the salient distractor features following similarity-based training to the point where the discordant category is reasonably learned. Indeed, some PNFA patients endorsed low distortion items with greater frequency than members. PNFA patients were also the only subject group to more frequently endorse test member items that were previously seen during training than members seen for the first time at test, following similarity-based training in both Experiments 1 and 2. Control subjects exhibited a similar pattern for the discordant category only. We assume that this "old item" advantage in controls reflects the relative difficulty they had in relating the discordant members to the prototype. The apparent reliance on memory for training items seen in the PNFA patients would thus suggest that this patient group had difficulty forming a representation of a prototype even for a category with strong inter-item resemblance. Thus, PNFA patients resemble healthy controls and SD patients in that they exhibit different judgment patterns for rule-based and similarity-based categorisation for the discordant category; however, they differ from controls and SD patients in their generally impaired rule-based processing, their inappropriate sensitivity to feature salience during rule-based processing, and their greater sensitivity to salience during similarity-based processing. These results are consistent with executive resource limitations, particularly poor inhibitory control.

Some previous observations suggested that PNFA patients have a semantic memory deficit for verbs and their associated actions (Bak et al., 2001; Grossman et al., 1996; Rhee et al., 2001). Because verbs do not fall into richly structured semantic categories compared to nouns (G. A. Miller & Fellbaum, 1991; G. A. Miller & Johnson-Laird, 1976), the meaning of action words may tend to involve defining features. Hence, verb knowledge may be more conducive to rule-based than to similarity-based categorisation. We speculate that limited rule-based semantic categorisation in PNFA may predispose the semantic category of actions to be difficult for these patients. A processing-based semantic deficit may not be evident in commonly used measures of object knowledge in PNFA because such measures tend to test knowledge of familiar objects composed of salient features, allowing patients to rely on their preserved similarity-based categorisation.

The greatest impairment in categorising our novel stimuli was demonstrated by nonaphasic patients with a disorder of executive and social functioning. In particular, EXEC/SOC patients showed graded judgments to a similar extent following both similarity-based and rule-based training. Thus, EXEC/SOC patients were unable to take advantage of the specific rule-based criteria we provided, and unlike SD and PNFA patients, showed no differentiation between the two categorisation processes. Moreover, they were the only subject group equally affected by feature salience in both processing conditions: The only observed effect of feature salience was the tendency to judge members from the concordant category with greater accuracy compared to the discordant category regardless of the training condition. Rule-based categorisation difficulty during judgments of novel categories paralleled EXEC/SOC patients' previously observed rule-based categorisation difficulty with familiar objects (Grossman et al., 2003b), suggesting that their deficit is not influenced by the familiarity or recency of knowledge represented in semantic memory. Instead, our results suggest that the semantic memory deficit in EXEC/SOC patients is related to a limitation of inhibitory control, selective attention, and/or working memory. These observations, along with the current study, emphasise that a semantic memory impairment does not necessarily depend on the presence of an aphasia.

SOC/EXEC patients' disorder of social functioning has been attributed to the degradation of social knowledge (Wood & Grafman, 2003). This domain is relatively unstructured and underspecified, and comprehension of social settings may depend in large part on rule-based categorisation. Thus, the findings in the present study suggest that EXEC/SOC patients' rule-based categorisation deficit may contribute to their difficulty processing social knowledge.

In conclusion, we have shown selective categorisation processing impairments in subgroups of FTD that support our two-component view of semantic memory. In addition, the varied patterns of impaired and spared processes argue against the view that categorisation is a unitary process in which difficulties simply reflect task demands (Nosofsky & Johansen, 2000; Nosofsky & Palmeri, 1998). Our findings suggest a predominant role for knowledge degradation in semantic dementia, contrasted with a rule-based processing impairment in other forms of frontotemporal dementia that stems in part from executive resource limitations. Although our findings are suggestive, further work is needed to specifically test the relative roles of represented knowledge and integrative processes. For instance, we have concluded that processing limitations stemming from executive resource impairments affect categorisation in PNFA and SOC/EXEC patients, and we have conjectured that such limitations partially account for deficits in verb knowledge in the former patient subgroup and deficits in social knowledge in the latter. However, the rule-based processing deficit that we have demonstrated cannot account for the differences in domains of semantic memory impairment in these two groups, suggesting some interaction between process and content. In addition, the generalisability of our findings should be tested by examining categorisation in other semantic domains, including verbs, abstract concepts, and other kinds of concrete objects (e.g., manufactured artifacts) that may differ from animals in how conducive they are to particular categorisation processes. Finally, to gain a fuller understanding of the causes of semantic memory deficits in FTD, longitudinal studies are needed to assess changes in the relative roles of process and content during the course of the disease.

Manuscript received 10 February 2004
Revised manuscript received 29 March 2005
Revised manuscript accepted 4 April 2005
PrEview proof published online 18 October 2005

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