Brain & Language 111 (2009) 8–19

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

A common mechanism in verb and noun naming deficits in Alzheimer's patients

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ARTICLE INFO

Article history:
Accepted 16 July 2009
Available online 21 August 2009

Keywords:
Nouns
Verbs
Alzheimer's
Semantic impairments
Category specific impairments
Picture naming

ABSTRACT

We tested the ability of Alzheimer's patients and elderly controls to name living and non-living nouns, and manner and instrument verbs. Patients' error patterns and relative performance with different categories showed evidence of graceful degradation for both nouns and verbs, with particular domain-specific impairments for living nouns and instrument verbs. Our results support feature-based, semantic representations for nouns and verbs and support the role of inter-correlated features in noun impairment, and the role of noun knowledge in instrument verb impairment.

1. Introduction

Semantic impairments in Alzheimer's disease (AD) have been central to several theoretical accounts of semantic memory, but much of the research on these impairments has focused on nouns (e.g., Bonilla & Johnson, 1995; Garrard, Lambon Ralph, Hodges, & Patterson, 2001; Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; Hodges & Patterson, 1995). Although nouns are an essential part of language, it is the lexical representation of verbs that is often considered most crucial for certain aspects of language processing, most notably sentence comprehension (e.g., Boland, Tanenhaus, & Garnsey, 1990; MacDonald, Pearlmutter, & Seidenberg, 1994). Recently, several researchers have recognized the importance of verb semantic performance for the overall understanding of semantic impairments in AD and have begun to explore verb performance in these patients (e.g., Druks et al., 2006; Fung et al., 2001; Grossman, Mickanin, Onishi, & Hughes, 1996; Grossman, Mickanin, Onishi, Robinson, & D'Esposito, 1997; Parris & Weekes, 2001; Robinson, Grossman, White-Devine, & D'Esposito, 1996). Despite these efforts, the extent and nature of verb impairments in this population remains controversial. The research reported here aims to advance our understanding of the verb impairments in AD by establishing whether theoretical constructs and models that have been developed to account for noun and verb naming impairments can explain the performance of AD patients. In particular, we investigate the implications of naming deficits for the previously hypothesized organization of semantic representations of nouns and verbs within a feature-based framework.

The semantic representation of abstract nouns and verbs is not well understood even in unimpaired populations and we therefore chose to only examine impairments to imageable nouns and verbs. Although this choice may restrict the generality of our results, it allowed us to address the broader theoretical implications of our finding by relating it to previous theoretical work on the semantic representation of concrete nouns. In particular, we wanted to see whether AD patients' verb impairment can be captured in the same feature-based distributed representation framework that several investigators have used to explain semantic deficits with concrete nouns (e.g., Aronoff et al., 2006; Devlin, Gonnerman, Andersen, & Seidenberg, 1998; Gonnerman et al., 1997; Saffran & Sholl, 1999; Shallice, 1993; Tyler & Moss, 2001). In a feature-based framework, conceptual knowledge is represented by connections between features and concepts, and the activation of concepts corresponds to a pattern of activation over distributed featural representations. In this framework, the relation between concepts is based on the number of features the two concepts share (featural overlap), which largely maps onto perceived similarity between concepts

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doi:10.1016/j.bandl.2009.07.009

(Maki, Krimsky, & Munoz, 2006; Rips, Shoben, & Smith, 1973; Tversky, 1977). Featural overlap also gives rise to other relations beyond similarity. For instance, "contrast coordinate" relations exist between concepts that differ in only a small number of features (e.g., *zebra* and *horse*), and "super-ordinate" relations exist when the features of one concept are a subset of another concept's features (e.g., *animal* and *horse*).

Although the majority of the work on the relationship between the structure and organization of the featural system and semantic performance has centered on concrete nouns (e.g., Cree & McRae, 2003; Garrard et al., 2001; McRae, de Sa, & Seidenberg, 1997), some researchers have also investigated the role of features in verbs (e.g., Bird, Howard, & Franklin, 2000; Miller & Fellbaum, 1991; Parris & Weekes, 2001; Vigliocco, Vinson, Damian, & Levelt, 2002; Vigliocco, Vinson, Lewis, & Garrett, 2004; Vinson & Vigliocco, 2002; Vinson, Vigliocco, Cappa, & Siri, 2003). The present research extends this previous work in two ways. First, we examined whether the general feature-based framework can account for verb performance in AD by testing a main prediction of this framework – graceful degradation (i.e., the gradual loss of function). Second, we tested the predictions of several specific feature-based models by comparing patients' performance with nouns and verbs from different semantic domains. We discuss each of these in turn.

A hallmark characteristic of the distributed feature-based framework is that it predicts graceful degradation, rather than complete dysfunction, as a result of small amounts of damage to the conceptual system. Graceful degradation occurs in this framework as a result of gradual loss of connections between features and the concepts which they represent, mirroring the likely neurodegenerative effect of AD (Farah & McClelland, 1991). With the progression of the disease, the number of available semantic features gradually decreases. As a result, differences between concepts diminish, even though the gross structure of semantic categories may remain largely intact initially (Aronoff et al., 2006). Thus, graceful degradation means that AD patients' performance on semantic tasks looks similar to unimpaired performance, except that it's poorer overall. The general preservation of semantic category structure at the initial stages of disease progression has been previously shown for nouns (Aronoff et al., 2006; Bonilla & Johnson, 1995; Ober & Shenaut, 1999), but no similar evidence currently exists for verbs. Because nouns and verbs differ in a variety of ways, their susceptibility to damage may be different. While concrete nouns tend to refer to individuated referents, verbs tend to describe relations (e.g., Gentner, 1981). Their semantic representations may be more dependent on the representations of other concepts, leading to faster breakdown of category structure. Moreover, because verb meaning is intimately connected to the syntactic structures the verb can appear in, verb impairments may appear all-of-a-piece with the decline of grammatical ability (Grossman et al., 1996; Kempler, Almor, Tyler, Andersen, & MacDonald, 1998). However, if the same feature-based organizational principles underlie the semantic representations of nouns and verbs, then AD patients' verb performance should also show graceful degradation in that patients should show greater difficulty with the same semantic categories that healthy controls find more difficult. The first goal of the present work was to test whether, similar to nouns, AD patients' verb performance resembles unimpaired performance, albeit at an overall lower level.

Graceful degradation also predicts consistent changes to the pattern of errors made by patients as the disease progresses (e.g., Bowles, Obler, & Albert, 1987; Gonnerman, Aronoff, Almor, Kempler, & Andersen, 2004; Hodges, Graham, & Patterson, 1995). This process occurs in the following way: When all the connections between features and the concepts they represent are intact, accuracy is expected to be high. With mild damage to these connections, most knowledge will be preserved, but if a distinguishing feature is affected then contrast coordinate errors may occur (e.g., saying *dog* for *cat*). Increasing damage will affect more distinguishing features which will likely result in a substantial loss of knowledge about specific concepts, reflected in a high number of super-ordinate errors (e.g., saying *animal* for *cat*). More extensive damage will lead to the loss of even general knowledge about concepts, which will likely be reflected in the occurrence of cross-category errors (e.g., saying *pear* for *cat*). Finally, with massive damage to the connections in the featural system, loss of knowledge of entire semantic categories may occur, resulting in the complete loss of naming ability for concepts from these categories, and leading to many *do not know* responses. Although the general pattern of noun naming errors exhibited by patients appears to support this prediction (Bowles et al., 1987; Gonnerman et al., 2004; Hodges et al., 1995), it is yet unclear whether the same error progression would also occur with verbs. Verb performance may not exhibit the same pattern of errors, given the conceptual differences between nouns and verbs (Gentner, 1981) and their differing syntactic roles (Grossman et al., 1996). However, if the same feature-based organizational principles underlie the semantic representation of nouns and verbs then verb naming errors should show similar patterns to nouns. The second specific goal of the present work was to test this prediction.

So far, we focused on whether verb performance in AD, at least for imageable verbs, could be explained in a feature-based framework on the basis of general mechanisms that are similar to the ones previously used to explain noun performance. We now turn to address the question of whether verb performance in AD may in fact show that verbs and nouns are represented in a single feature-based system. The general feature-based approach does not necessarily entail shared representations for nouns and verbs, and different researchers working in this framework have taken different positions about this issue. For example, in research on general models of semantic memory, Miller and Fellbaum (1991) described a feature-based network model in which nouns and verbs are represented separately, but Vigliocco et al. (2004) modeled the semantic representation of objects and actions within a single unitary feature-based system.

In the context of semantic impairments, Bird et al. (2000) proposed a model of semantic impairments in which nouns and verbs are represented in a single unitary feature-based semantic system. Following Warrington and McCarthy's (1987) and Warrington and Shallice's (1984) seminal work on nouns, Bird, Howard, and Franklin argued that verbs are similar to non-living nouns, in that they rely on a relatively low proportion of sensory to functional features. Their model predicts an association between performance with non-living nouns and verbs, which they confirmed by testing a small group of patients with aphasia. Parris and Weekes (2001) extended this approach to predict an association between performance with nouns and performance with instrument verbs, which encode a typical instrument as part of their core meaning (e.g., *sweeping*). In support of their model, Parris and Weekes described an anomic patient with dementia who showed worse performance with nouns than with verbs, but also a more subtle category specific verb deficit, with instrumental verbs being more impaired than non-instrumental verbs.

A plausible extension of this model is that, due to the importance of instrument information for the semantic representation of instrument verbs, coupled with the fact that those instruments tend to belong to non-living noun categories, semantic performance with instrument verbs would be associated with non-living noun performance more than with living nouns performance. Although Parris and Weekes (2001) acknowledged this implication of their model, the single patient that they tested was completely impaired with all nouns, and they were therefore unable to test this prediction directly. Here we tested this prediction of the Parris and Weekes model by comparing instrument verb performance and relative non-living and living noun performance in a group of AD patients with various levels of impairment. Following the same logic, we reasoned that performance with verbs that rely on sensory information would be associated with performance with nouns that describe living things more than with nouns that describe non-living things. We, therefore, also looked at manner verbs whose meaning encodes the manner of the action they describe (e.g., *run*, *skip*, and *walk*), which, by some accounts (Marshall, Chiat, Robson, & Pring, 1996; Marshall, Pring, Chiat, & Robson, 1996), is primarily sensory (e.g., ⟨quick movement⟩ is a perceptual/visual feature that distinguishes *running* from *walking*). Under this view, the Bird, Howard, and Franklin, and Parris and Weekes models should predict a stronger association between performance with manner verbs and living nouns.

In addition to the distinction between sensory and functional features, some researchers also consider the likelihood with which features co-occur in the representation of different concepts (feature inter-correlation; e.g., animals that ⟨have a beak⟩ tend to also ⟨fly⟩) as an important predictor of semantic impairments (Devlin et al., 1998; Gonnerman et al., 1997; Moss, Tyler, & Jennings, 1997). Garrard et al. (2001) and McRae et al. (1997) analyzed differences in the prevalence of inter-correlated features in different semantic noun categories and found that living noun categories had more inter-correlated features than non-living categories. Due to the differences in the number and type of inter-correlated features in different domains, several researchers have used feature inter-correlation to explain domain-specific deficits with nouns. Gonnerman et al. (1997) argued that the semantic representation of living things is protected from small amounts of damage by the high prevalence of feature inter-correlation. If one feature in an inter-correlated cluster is damaged, the rest of the features in the cluster can still lead to sufficient activation of the concept. In contrast, because non-living concepts tend to depend on idiosyncratic features, damage to one feature is more likely to impair performance with any non-living concept that relies on that feature. Moss et al. (1997) applied a similar logic but also differentiated between distinctive and shared features. They noted that distinctive features tend to appear in inter-correlated clusters more often in the representation of non-living nouns, for which shape and function are often related than in the representation of living things, for which distinguishing features tend to be idiosyncratic.

According to both approaches, a small amount of damage would mostly affect concepts with idiosyncratic features and few inter-correlated features, but more excessive damage would affect entire feature clusters and therefore impair entire groups of concepts that share these clusters. Consequently, both approaches predict a relation between the amount of damage to the semantic system and relative performance with concepts from different semantic domains. However, the two approaches differ in which semantic domain they predict would be more affected by small and large amounts of damage to the semantic system. The Gonnerman et al. approach predicts that with small amounts of damage to the semantic system, non-living nouns would be more impaired than living nouns and that later in the disease this pattern would switch. Moss, Tyler, and Jenkins make exactly the opposite prediction.

Because the role of feature inter-correlation is a matter of debate, and because most of the empirical work in this area has not considered verb performance, it is important to test empirically whether the relation between features can explain performance patterns in both nouns and verbs. Thus, the third and final specific goal of this work was to test predictions of specific feature-based accounts. Accounts based on the sensory-functional distinction predict an association between patients' relative performance with nouns vs. verbs and (a) their relative performance with non-living vs. living nouns, and (b) their relative performance with instrument vs. manner verbs. Accounts that are based on feature inter-correlation predict an association between patients' naming accuracy and (a) their relative impairment with non-living vs. living nouns, and (b) their relative impairment with instrument vs. manner verbs.

To summarize, the present research addressed three main questions:

1. Is verb performance in AD compatible with graceful degradation in a general feature-based framework such that relative levels of naming performance are preserved across different categories?
2. Is verb performance in AD compatible with graceful degradation in a general feature-based framework in terms of error pattern progression (i.e., super-ordinate errors → contrast coordinate errors → cross-category errors → "do not know" errors)?
3. Do patterns of noun and verb category impairments support the sensory-functional models of Bird et al. (2000), and Parris and Weekes (2001), and/or the feature inter-correlation models of Gonnerman et al. (1997) or Tyler and Moss (2001)?

We addressed these questions using a timed picture naming task because this task has been used to successfully assess lexical semantic performance in AD patients (e.g., Gonnerman et al., 1997). The relative simplicity of this task allowed us to employ a much larger set of stimuli than would have been possible with more complex stimuli such as animations. Because response times are not likely to show ceiling effects in the same way as accuracy scores, we also measured naming latencies (Druks et al., 2006). The pictures were selected from six non-living noun categories, six living noun categories, six instrument verb categories, and six manner verb categories. Throughout the rest of this paper we shall use the term "semantic domain" to distinguish between living and non-living objects and between instrument and manner verbs. We shall use the term "semantic category" to refer to individual categories such as "zoo animals" or "vehicle motion" verbs. We shall also use the term "word class" to distinguish between nouns and verbs. To ensure sufficient performance variability and avoid ceiling effects, pictures varied in naming difficulty and included pictures which pilot data indicated were difficult to name.

2. Methods

2.1. Participants

Fourteen patients with AD and fourteen healthy elderly normal controls (EN) participated in this study. Table 1 shows participants' demographic and Mini-Mental State Exam (MMSE) scores. The two groups were matched for age, $t(13) = 1.6$, *n.s*., and years of education, $t(13) = -1.68$, *n.s*., but the patients had lower MMSE scores, $t(13) = 1.6$, $p < .001$. Participants were paid for their participation. The AD patients were diagnosed with probable Alzheimer's disease using the NINCDS-ADRDA criteria (McKhann et al., 1984). Results of neurological, laboratory (including computer tomography or magnetic resonance scan), and neuropsychological assessment failed to suggest other causes of dementia. All participants were native speakers of standard American English. All recruitment, informed consent, and testing procedures were approved by the University of Southern California's Institutional Review Board (IRB).

Table 1
Participants' age, level of education, MMSE and naming performance.

Age	Education	MMSE	Accuracy (% correct)				RT (ms)			
			Nouns		Verbs		Nouns		Verbs	
			Living	Artifact	Instrument	Manner	Living	Artifact	Instrument	Manner
EN										
86	18	29	68	68	38	33	1284	1047	1436	1065
81	18	30	85	92	49	49	946	911	943	1084
81	16	29.5	80	77	49	43	1590	1314	2182	1589
88	17	28.5	68	70	52	39	1375	1359	1480	1508
83	14	30	83	86	56	51	1072	1023	1352	1269
75	12	30	75	83	53	52	1097	1085	1033	1127
83	16	29.5	85	88	51	45	1132	1030	1155	1331
81	20	30	87	91	53	50	1239	1175	1479	1355
77	15	28	94	91	60	55	1034	972	1169	1395
80	16	29.5	97	89	51	56	978	1037	1118	1154
78	16	29	75	79	43	42	1102	1084	1112	1334
77	16	27	90	85	57	46	985	929	1251	1433
75	14	28.5	96	97	61	54	848	782	886	904
81	18	29.5	81	79	40	36	879	887	1469	1421
AD										
78	16	23	69	72	52	46	996	999	1273	1144
80	21	22	71	79	44	48	1065	1037	1308	1313
85	12	16.5	41	56	33	36	-	-	1821	1463
85	13	22.5	25	28	10	22	1040	1245	1618	1668
79	12	16.5	17	33	16	20	1274	1209	1589	1794
82	12	21.5	74	82	43	41	1187	1235	2135	1883
81	16	19	69	77	49	41	961	1091	1201	1268
86	19	21.5	65	68	35	36	1119	987	1330	1145
80	14	24	87	83	48	43	1455	1481	2272	2222
87	12	17	49	59	26	23	1509	1379	1918	1423
87	12	17.5	81	78	34	28	2002	2253	2283	2295
80	18	20.5	44	56	25	30	1498	1488	2004	1738
84	12	20.5	82	85	41	35	1120	1142	1810	2318
82	14	24.5	77	85	41	45	1010	983	917	852

2.2. Materials

2.2.1. Nouns

One hundred and forty-four nouns describing depictable objects from six living and six non-living categories (12 nouns from each category) were selected. The living and non-living nouns were matched for mean word frequency (Francis & Kučera, 1982) and familiarity. Familiarity scores were taken from both the Snodgrass (Snodgrass & Vanderwart, 1980) and the MRC database (Wilson, 1988). The ratings from each source were first z transformed in order to bring the ratings from both sources to a uniform scale. For nouns that had ratings in both sources, the average of the two z scores was used as the familiarity score for that noun. For nouns that had a familiarity rating in only one source, the z transformed rating of that score was used instead. The list of all nouns appears in Appendix A. A matching color picture was then selected for each noun from various print and on-line sources, or photographed and edited to yield a clearly identifiable picture of the object on a white background at an 800×600 screen resolution.

2.2.2. Verbs

Ninety-six verbs from six manner and six instrument categories (eight verbs from each category) were selected based on Levin's (1993) classification. As with the nouns, the manner and instrument verbs were matched for word frequency (Francis & Kučera, 1982). Because we were unable to find published familiarity ratings for most of our verbs, we collected familiarity ratings from 67 University of Southern California undergraduates recruited through the Psychology Department's participant pool. Participants were asked to rate how familiar they thought the action described by each verb was on a scale from 1 to 7 (with seven being the most familiar). The familiarity of the instrument verbs, $M = 5.88$, $SD = .61$, did not differ from the familiarity of manner verbs, $M = 5.94$, $SD = .6$, $t(47) = .52$, *n.s.* Because different verbs can vary in how imageable they are (much more so than the concrete nouns we used) and because imageability can affect picture naming performance, we wanted to ensure that the instrument and manner verbs we selected did not differ in imageability. We therefore ran an imageability rating study in which 30 different undergraduate participants from the University of Southern California Psychology Department participant pool rated the imageability of the different verbs on a scale from one to seven with seven being most imageable. The imageability of the instrument verbs, $M = 5.01$, $SD = .81$, was not different than the imageability of the manner verbs, $M = 4.78$, $SD = .67$, $t(47) = 1.49$, *n.s.* The list of all verbs can be found in Appendix B. Color pictures were selected and prepared similar to the nouns.

In choosing the concepts for the naming task, our goal was to use items that were namable, but would minimize any ceiling effect for the control subjects. Twenty five paid young participants (ages 17–27, mean: 20.2) recruited through bulletin board advertisements named all the nouns and verbs based on the pictures used in the experiment. Noun categories ranged in accuracy from 73% to 95% (mean = 86%) and verb categories ranged in accuracy from 73% to 96% (mean = 82%). Naming agreement was also calculated for the norming data as the number of intended target responses divided by the number of semantically correct responses, which included, in addition to the intended target responses, synonyms, and expressions that had greater detail than the target (i.e., subordinate). Overall naming agreement was high: 87% for verbs and 90% for nouns. Given that age of acquisition has been recently shown to be an important factor in explaining naming performance in AD we had ninety nine University of South Carolina undergraduate students rate the age of acquisition of our stimuli following the procedure of Gilhooly and Gilhooly (1980). The nouns and the verbs in our study were both rated as having the same average age of acquisition of 4.5 years.

2.3. Procedure

The object and action naming tasks were conducted in separate sessions at least two weeks apart. Half of the participants from each group performed the verb naming task first and the other half performed the noun naming task first. To minimize order related confounds we used two random orderings of the stimuli for each task and tested half of the participants from each group with each ordering. Stimuli presentation and response recording were controlled by an Apple Powerbook G3 computer running Psyscope 1.1 (Cohen, MacWhinney, Flatt, & Provost, 1993) with a PSI button box. The testing session was also audio taped for later verification and transcription. All testing was conducted in a quiet room at participants' home, nursing home, or the University of Southern California's campus.

Each task started with instructions followed by a short practice block. The experimenter verified that all participants understood the task before they started the actual experiment. Participants were instructed to name the pictures as quickly and accurately as they could. In the noun task, they were instructed to name the object presented on the screen and in the verb task they were asked to name the action shown using a verb in the –ing form. A voice key was used to record the latency between the onset of the picture on the screen and the initiation of vocal response. The picture was removed from the display when a response was detected by the voice key. Participants received no feedback during the experiment.

Responses were transcribed by the experimenter during the experiment and were verified using the audio tapes after the experiment. Responses were then coded using the following criteria (see Table 2 for summary and examples). A response that was either the target word, a synonym of the target word, or a subordinate term of the target word was coded as "correct". Incorrect responses that were semantically related to the target were classified into "contrast coordinate", "super-ordinate", and "other" errors. The "other" category consisted of responses that were somehow semantically related to the target but did not fall into any of the previous categories. Incorrect responses that were not semantically related to the target were classified as "cross-category" responses, and responses that correctly described an unintended aspect of the target picture were coded as "alternates" and together with trials in which equipment error prevented stimulus presentation were dropped from further analyses. When participants indicated not being able to name the picture their response was coded as "do not know." In addition to the naming task, all participants also completed the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975).

Due to equipment malfunction, noun naming latencies from one AD patient were not properly recorded and were therefore not included in the response time analyses.

Because our stimuli were deliberately chosen to avoid ceiling effects with the healthy control participants, we did not expect the healthy control participants to name all the pictures correctly (see Table 1 for individual participants' performance). Therefore, to assess patients' impairment, it was important to assess their performance in relation to the performance of the control participants. To this end, we calculated impairment scores for the patients that were based on the difference between each patient's performance and the mean performance of the EN group, divided by the mean performance of the EN group. The purpose of dividing by the mean performance of the EN group was to ensure that the different impairment measures had the same scale. For example, a patient's "noun accuracy impairment score" was calculated as follows:

$$\frac{\overline{Noun\ accuracy}_{EN} - Noun\ accuracy_{patient}}{\overline{Noun\ accuracy}_{EN}}$$

Similar formulae were used to calculate for each patient an accuracy impairment score for verbs, living nouns, non-living nouns, manner verbs, and instrument verbs. In order to assess several relative impairments, we also calculated for each participant three impairment difference scores. For example, a patient's "noun–verb" accuracy impairment difference score was calculated by:

$$Noun\ accuracy\ impairment\ score_{patient} - Verb\ accuracy\ impairment\ score_{patient}$$

Living–non-living and manner–instrument impairment difference scores were calculated similarly. We also calculated impairment scores for all the latency measures but because these latency impairment scores yielded no significant effects in any of the analyses we don't report them.

3. Results and discussion

In order to ensure that our results were not affected by a baseline noun vs. verb impairment in the AD patients, we examined

Table 2
Picture naming response coding scheme.

Code	Explanation	Noun example	Verb example
Correct	Correct	"Rattle" for rattle	"Marrying" for marrying,
	Synonymous	"Hatchet" for axe	"Nursing" for breast feeding
	Subordinate	"Kitten" for cat	"Punching" for boxing
Contrast coordinate	Wrong word that describes an object or an action from the same category as the target verb	"Pear" for plum	"Rowing" for sailing
Super-ordinate	A super-ordinate of the target noun or verb	"Animal" for moose	"Walking" for tiptoeing
Other related responses	1. Neologism	"Mooer" for cow	"vising" for clamping
	2. Verb name for noun	"Mixing" for mixer	
	3. Noun name for verb		"Hurdles" for hurdling
	4. General phrasal response	"Put food in there" for bowl	"Trying to close something" for chaining
Do not know	When the participant said they did not know the target object or action		
Alternative responses and equipment errors	1. An alternative accurate description of some non intended aspect of the picture	"ABC" for a picture of play blocks with letters on them	"Standing" for panting
	2. A computer error		
Cross-category	A wrong response that does not fit any of the categories above	"Airplane" for a grasshopper	"Lighting" for flossing

naming accuracy for nouns and verbs in the two groups (Fig. 1a). Accuracy data were analyzed once with participants as a random factor (F1) and once with items as a random factor (F2). The participants analysis used a mixed design ANOVA with Group (EN, AD) as a between factor and Word Class (Noun, Verb) as a within factor. The items analysis used a mixed design ANOVA with Group as a within factor and Word Class as a between factor (unless noted otherwise, all the subsequent analyses we report in this paper followed a similar format). These analyses found a significant effect of group with healthy controls responding more accurately than the patients, $F1(1, 26) = 13.83$, $p < .001$, $F2(1, 237) = 296.10$, $p < .001$, a significant effect of word class with nouns named more accurately than verbs, $F1(1, 26) = 304.99$, $p < .001$, $F2(1, 238) = 22.63$, $p < .001$, and no interaction between group and word class, $F1(1, 26) = 2.86$, *n.s.*, $F2 < 1$. Thus, although patients were more impaired than healthy controls in naming both nouns and verbs, they were not disproportionately impaired with verbs.

3.1. Noun vs. verb RT

The latencies of correct naming responses (Fig. 1b) were analyzed similarly to the accuracy data. To reduce the effect of outliers, in this and all subsequent response time analyses, participant median correct response times were used for the participant analyses and item median correct response times were used for the item analyses (Ratcliff, 1993). Twelve verb items and eleven noun items with one or less RT data point from any group (due to naming error or equipment problems) were excluded from these analyses. As in the accuracy analyses, the response time analyses found a significant effect of group with patients responding slower than the EN group, $F1(1, 25) = 5.55$, $p < .03$, $F2(1, 215) = 79.39$, $p < .001$, a significant effect of word class with nouns named more quickly than verbs, $F1(1, 23) = 46.90$, $p < .001$, $F2(1, 215) = 31.50$, $p < .001$, and a marginally significant interaction between group and word class in the participants analysis but not the items analysis, $F1(1, 37) = 4.09$, $p < .06$, $F2(1, 215) = 1.91$, *n.s.* The response time analyses therefore corroborate the accuracy analyses in showing a robust overall impairment in AD patients but no strong evidence for disproportionate verb impairment in the patients. We next consider the possibility that this trend failed to achieve statistical significance due to variability among the patients related to the state of their disease or other personal characteristic.

3.2. Noun, verbs, and participant characteristics

To test whether other patient characteristic affected the patients' relative performance with nouns and verbs we calculated the correlations between participants' noun–verb accuracy impairment scores, and their MMSE, age, education, and overall accuracy. We used Rom's method (Rom, 1990) to control for family wise error. We found that patients' noun–verb accuracy scores were strongly correlated with age such that older age was linked with a more pronounced verb deficit, $r = -.72$, $t(13) = -3.47$, $p < .05$ (Fig. 2). No other correlation was significant. We calculated the same correlations for patients' noun–verb latency impairment scores but found no significant or close to significant correlations. We also calculated the correlations between the noun and verb performance MMSE, age, education, and overall level of performance for the EN group but found no significant or close to significant correlations.

Thus, our results show that if there are differences between the effects of AD on verbs and on nouns, these differences are subtle and appear related to the catalyzing effect AD may have in making age effects more easily discernable. We now turn to address the three questions.

1. Is verb performance in AD compatible with graceful degradation in a general feature-based framework in terms of the general preservation of unimpaired category structure?

Given that AD affects both noun and verb naming, we wanted to ascertain whether AD patients' impaired performance resembles unimpaired performance at an individual semantic category level. Fig. 3 shows both groups' naming accuracy and correct response latency for individual noun and verb categories. To quantitatively assess the similarity in relative category performance, we calculated the correlations between the average performance of the AD and EN groups for the 12 noun categories and for the 12 verb categories. The two groups' naming accuracy for different semantic categories were strongly correlated for both nouns, $r = .82$, $t(11) = 4.6$, $p < .001$, and verbs, $r = .84$, $t(11) = 4.80$, $p < .001$, and the difference between these correlations was not statistically significant, *Fisher's* $Z = -.14$, *n.s.* Similarly, the two groups' correct response latencies for different semantic categories were also correlated for both nouns, $r = .72$, $t(11) = 3.24$, $p < .01$, and verbs, $r = .88$, $t(11) = 5.86$, $p < .001$, and the difference between these correlations was not statistically significant, *Fisher's* $Z = -.99$, *n.s.* These analyses therefore reveal that for both nouns and verbs, patients' relative naming of pictures from the various semantic categories paralleled unimpaired naming performance. This shows that for both nouns and verbs, AD results in graceful degradation.

2. Is verb performance in AD compatible with graceful degradation in a general feature-based framework in terms of error pattern progression?

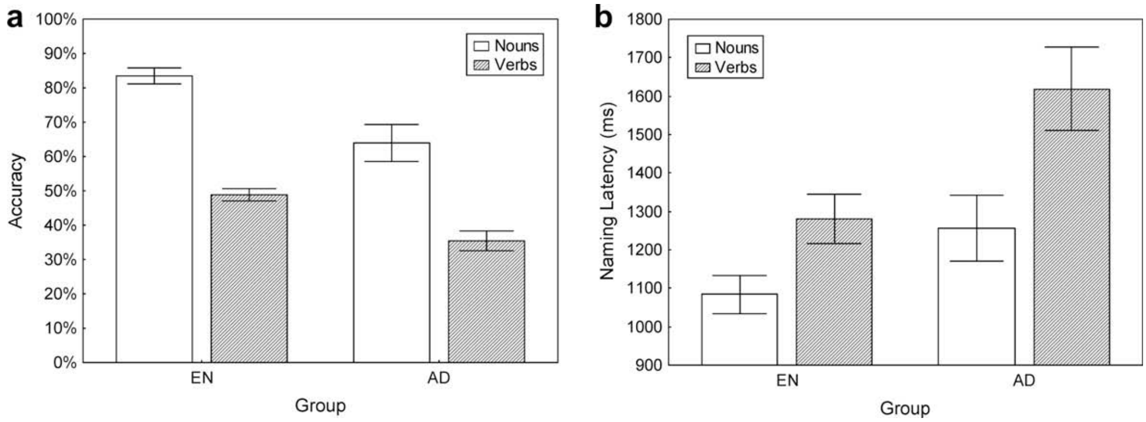

Fig. 1. Noun and verb naming accuracy (a) and naming latency (b) for both groups. Error bars show the standard error of the mean.

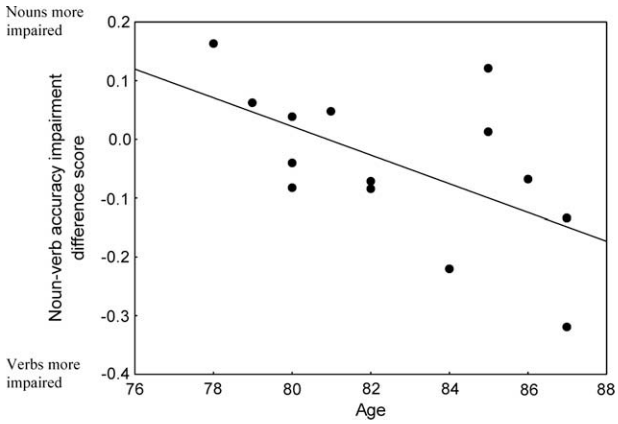

Fig. 2. The relation between patients' age and noun–verb accuracy impairment difference scores.

To test whether, for both nouns and verbs, naming errors progress from contrast coordinate to super-ordinate to cross-category and finally to ''do not know'' responses, we compared the number of each of the four error types in the two populations for nouns and verbs. We did not include the ''other'' errors in these analyses because responses in this category could not be clearly classified by semantic specificity. We calculated error percentages for each participant by dividing the number of errors of each type made by the participant by the total number of errors from the four types he or she made. This calculation was done separately for nouns and for verbs. Fig. 4 shows the mean percentages for both groups in naming noun and verb pictures. As is evident in the figure, error patterns showed the predicted shift for both nouns and verbs. To ascertain whether this shift in error distribution was statistically significant we rank ordered the errors (contrast coordinate = 1, super-ordinate = 2, cross-category = 3, do not know = 4) and used the Brunner–Munzel test (Brunner & Munzel, 2000) to compare the ranking of the errors made by the two groups. The ranking of

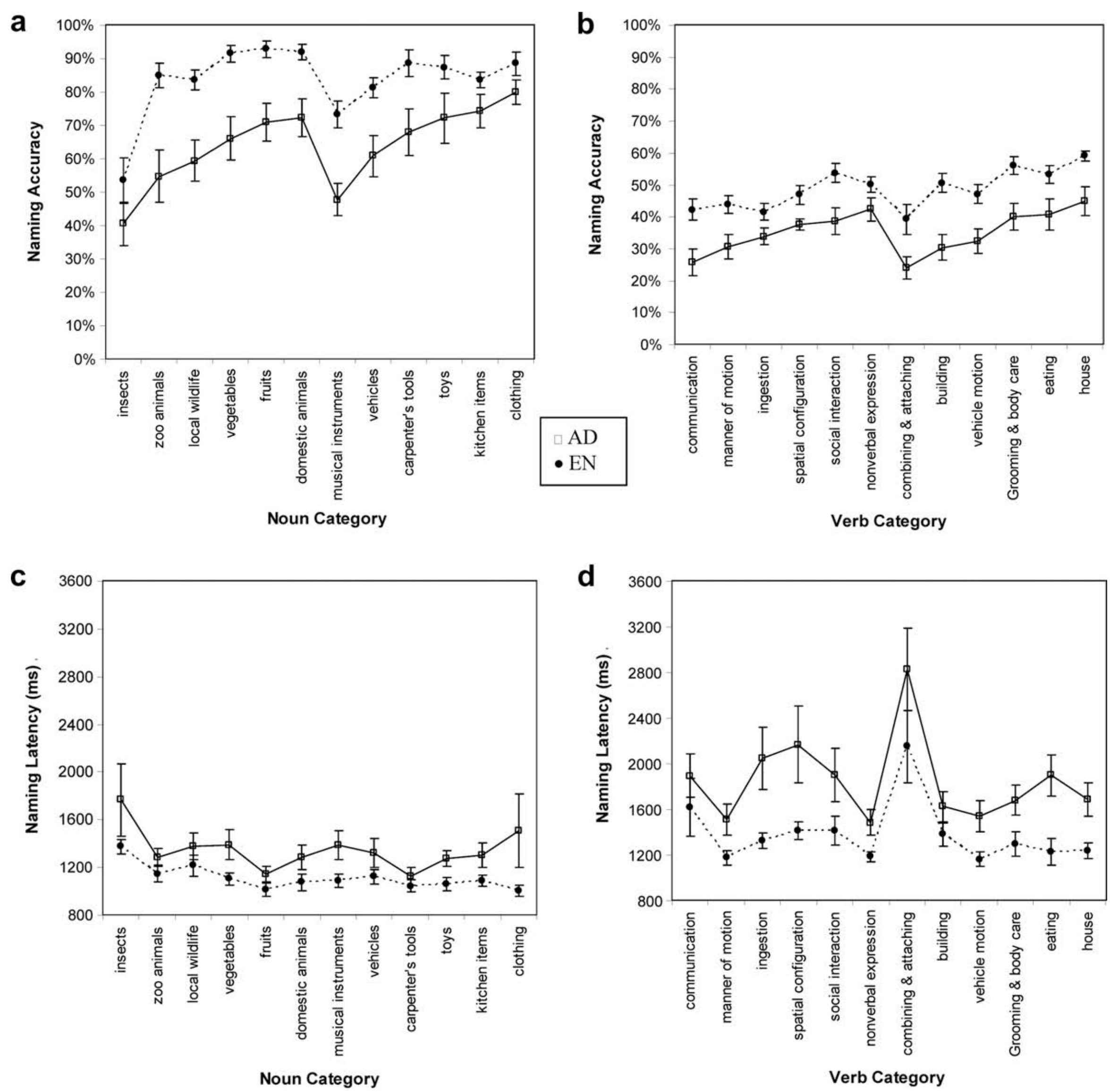

Fig. 3. Naming accuracy and correct response latencies by category for nouns and verbs. Categories are sorted from right to left by semantic domain (living vs. non-living nouns and instrument vs. manner verbs) and by AD patients accuracy within each domain. A line graph is used to highlight the similarity in the overall pattern of the two groups and not as indicating an underlying continuous scale. Error bars show the standard error of the mean.

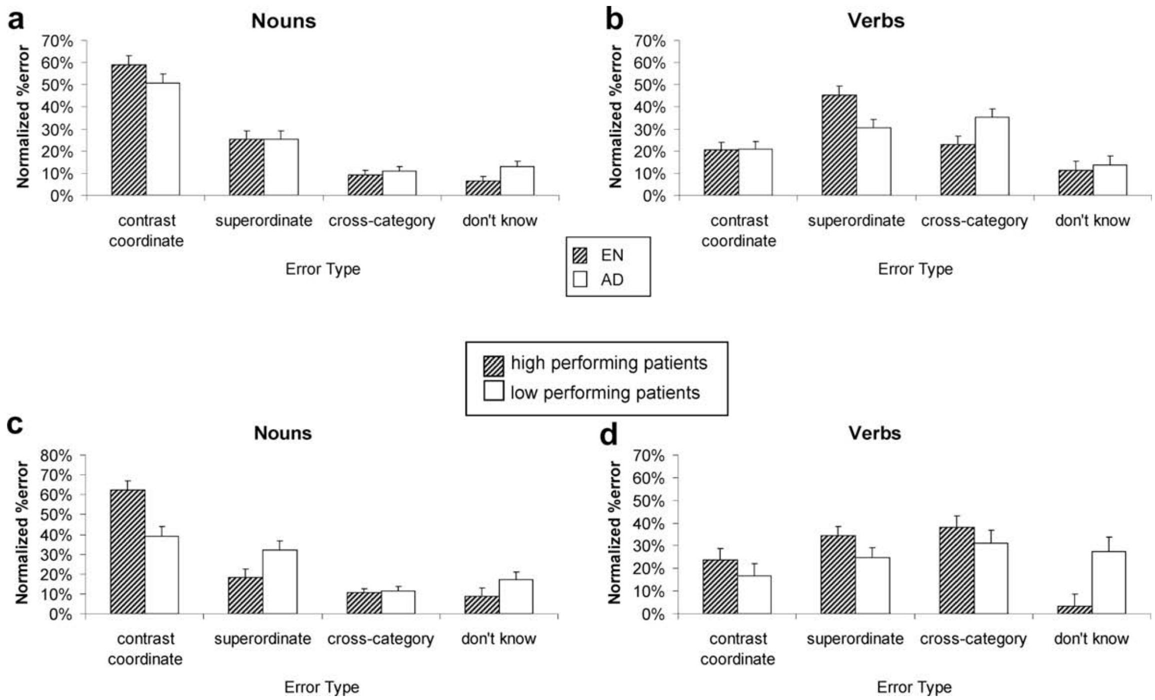

Fig. 4. Distribution of semantic errors for nouns and verbs for the EN and AD groups and for high and low performing AD subgroups. Error rates are shown as percentages from the total number of semantic errors (contrast coordinate, super-ordinate, cross-category, and do not know). Error bars show the standard error of the mean.

errors was higher for the AD patients than for the EN group for both nouns, *Brunner–Munzel Statistic* (693.5) = 3.54, $p < .001$, and verbs, *Brunner–Munzel Statistic* (542.8) = 2.30, $p < .03$.

To further test whether poorer naming performance in the patients is associated with the predicted shift in error progression, we used a median split based on overall accuracy to divide the AD group into a high performing and low performing group. This was done separately for nouns and verbs. The relative error percentages of these two groups are shown in Fig. 4c for nouns and in Fig. 4d for verbs. We again used the Brunner–Munzel procedure to test whether the two patient groups significantly differed in their error distribution. Again, the ranking of errors was higher for the low performing AD patients than for the high performing ones for both nouns, *Brunner–Munzel Statistic* (371.5) = 5.69, $p < .001$, and verbs, *Brunner–Munzel Statistic* (347.2) = 4.49, $p < .001$.

Thus, the general trend of changes in the error distribution was compatible with graceful degradation as predicted by the feature-based framework. At this point we can therefore conclude that a feature-based framework is generally compatible with both noun and verb performance in AD. Our next analyses aimed to test several specific proposals about the organization of feature-based systems.

3. Do patterns of noun and verb category impairments support the sensory-functional models of Bird et al. (2000), and Parris and Weekes (2001), and/or the feature inter-correlation models of Gonnerman et al. (1997) and Tyler and Moss (2001)?

To test whether patients showed domain-specific deficits in line with these theoretical accounts, we compared accuracy for living and non-living nouns and for manner and instrument verbs (Fig. 5). We initially analyzed the noun data and verb data separately. In both cases, the participants analyses used a mixed design ANOVA with Group (EN, AD) as a between factor, and Semantic Domain (living vs. non-living for nouns and manner vs. instrument for verbs) as a within factor. The items analyses used a mixed design ANOVA with Group as a within factor and Semantic Domain as a between factor. We also conducted similar analyses of correct naming latencies but because these analyses did not find any sig-

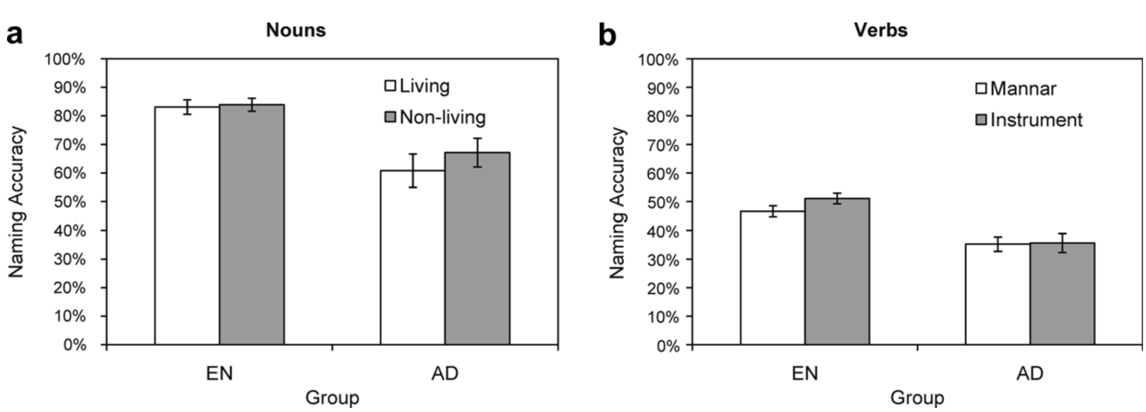

Fig. 5. Naming accuracy for living and non-living nouns (a) and manner and instrument verbs (b). Error bars show the standard error of the mean.

nificant effects except for the overall slower responses of the patients we do not report them.

For nouns, these analyses found a significant effect of group with patients responding less accurately than controls, $F1(1, 26) = 11.08$, $p < .003$, $F2(1, 141) = 186.254$, $p < .001$, an effect of semantic domain with more accurate naming of non-living than living nouns that was only significant by participants, $F1(1, 26) = 12.62$, $p < .002$, $F2(1, 141) = 1.49$, *n.s.*, and an interaction between group and semantic domain that was significant by participants and marginally significant by items, $F1(1, 26) = 7.67$, $p < .02$, $F2(1, 141) = 4.15$, $p < .07$. Tukey HSD post hoc tests indicated that the non-living nouns were named more accurately than the living nouns by the AD group, $p < .001$, but no significant difference was found for the EN group, $p > .9$. These analyses indicate that patients showed a disproportionate impairment for living nouns.

For verbs, these analyses found a significant effect of group with patients responding less accurately than controls, $F1(1, 26) = 15.81$, $p < .001$, $F2(1, 94) = 122.66$, $p < .001$, an effect of semantic domain with instrument verbs named more accurately than manner verbs that was only significant by participants but not by items, $F1(1, 26) = 6.10$, $p < .03$, $F2(1, 94) = 1.68$, *n.s.*, and an interaction between group and semantic domain that was significant by participants but not by items, $F1(1, 26) = 4.27$, $p < .05$, $F2(1, 94) = 1.33$, *n.s.* Tukey HSD post hoc tests indicated that the difference between naming accuracy for manner and instrument verbs was significant for the EN group, $p < .02$ (with instrument verbs named more accurately than manner verbs), but not for the AD group, $p > .9$. These analyses show that patients exhibited a disproportionate impairment for instrument verbs. However, the differences between the participant and items analyses for verbs indicate considerable variability among the verbs in each semantic domain.

Overall, these results indicate that, as a group, the AD participants showed a domain-specific deficit for living nouns and for instrument verbs. Together with the analyses that showed that our patients do not have a disproportionate verb impairment, these results argue against Bird, Howard, and Franklin's (2000) general suggestion that artifact and verb impairments are linked, and with Parris and Weekes's (2001) more specific claim about associations between non-living nouns and instrument verbs. However, analyzing mean group performance may be inadequate for testing the claims of these models because the group means do not reflect individual patterns of impairment that may be consistent with these views, but, when averaged, may contradict them. Our final set of analyses therefore tested the predictions of the different feature-based theories by examining specific associations between naming performance of nouns and verbs from different domains in individual patients.

3.3. *Bird et al. (2000)*

In order to test the relation this view predicts between noun–verb and living-non-living noun impairments, we calculated the correlation between the respective impairment accuracy scores. In support of the Bird, Howard and Franklin approach, we found that patients' noun–verb impairment accuracy impairment scores were significantly correlated with their living–non-living impairment accuracy scores, such that better accuracy with nouns relative to verbs was associated with better accuracy with living relative to non-living nouns, $r = .54$, $t(13) = 2.2$, $p < .05$ (see Fig. 6).

3.4. *Parris and Weekes's (2001)*

To test whether, as this view predicts, better performance with instrument verbs vs. manner verbs is linked to better noun performance we examined the correlation between patients' manner–instrument impairment difference scores and their noun accuracy. This correlation was significant, $r = .57$, $t(13) = 2.43$, $p < .04$, such that a more pronounced impairment with instrument than with manner verbs was associated with worse noun naming accuracy, therefore supporting the core claim of this model (see Fig. 7a). To test whether the extension of this model to an association between relative living–non-living noun impairment and relative manner–instrument verb impairment, we examined the correlation between the respective impairment accuracy scores. We found no significant correlation between the two impairment scores, $r = -.36$, $t(13) = -1.32$, *n.s.* Thus, our results support the core claim of the Parris and Weekes model about the differential importance of object knowledge in different verb categories but fail to support the extension of the model to more specific relations between non-living nouns and instrument verbs.

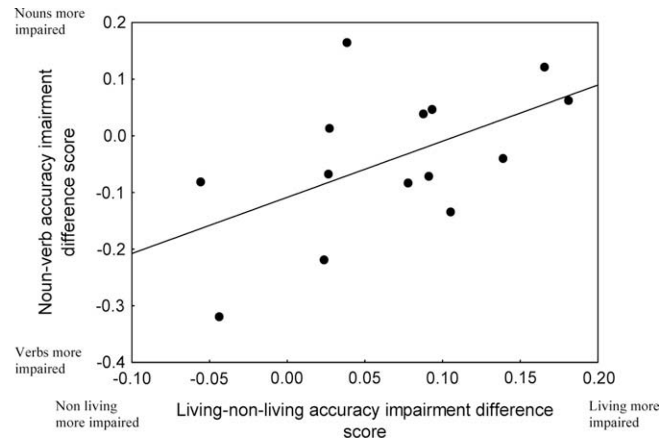

Fig. 6. The relation between AD patients' noun–verb and living–non-living accuracy impairment difference scores.

3.5. *Gonnerman et al. (1997)* and *Tyler and Moss (2001)*

To test whether, in line with these approaches, overall accuracy was associated with systematic changes in relative domain performance in nouns, we examined the correlation between patients' noun naming accuracy and their living–non-living impairment difference scores. This correlation was significant, $r = -.56$, $t(13) = -2.34$, $p < .04$, such that worse noun naming accuracy was associated with a more pronounced impairment with living than with non-living nouns (Fig. 7b). This result is compatible with the Gonnerman et al. (1997) view, but is contrary to the predictions of Tyler and Moss (2001). In order to examine whether domain-specific performance in verbs shows a similar pattern, we examined the correlation between patients' average verb performance and their manner–instrument impairment difference scores but found that this correlation was not significant, $r = .42$, $t(13) = 1.6$, *n.s.* Thus, while feature inter-correlation may be an important factor in relative impairment to living and non-living nouns, we found no indication that it plays a similar role in the relative impairment to manner and instrument verbs.

4. General discussion

By using a large set of items that varied in difficulty, we were able to examine noun and verb performance in both healthy control participants and patients with AD in a manner that minimized ceiling effects in the healthy control group and floor effects in the AD group. As expected, AD patients' naming difficulties resulted in

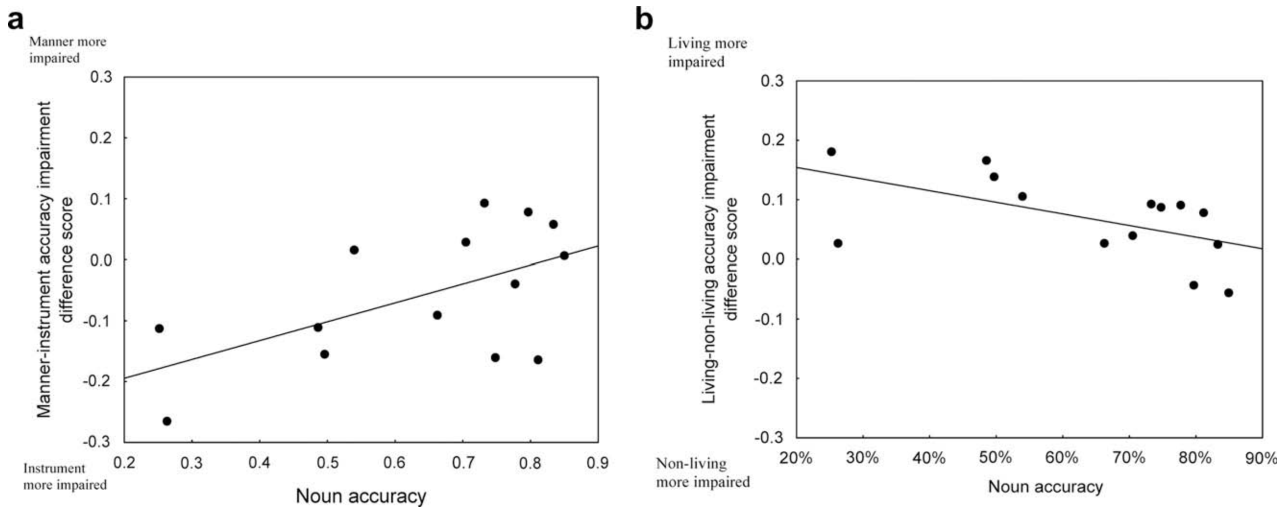

Fig. 7. The relation between patients' noun accuracy and their (a) living–non-living impairment difference scores and (b) manner–instrument impairment difference scores.

lower accuracy and longer naming latencies than the healthy control participants across all conditions. Although the AD patients in our study demonstrated worse performance for verb than noun naming, the overall magnitude of our patients' deficit was comparable for nouns and verbs. If there were any differences in the extent of impairment for the two word classes, these differences were subtle and likely related to the effect of age, which the disease may have amplified.

Our first question was whether verb performance in AD is compatible with graceful degradation of connections between features and concepts in a general feature-based framework in terms of the general preservation of unimpaired category structure. Our analyses demonstrated a reliable correlation between the performance of the two groups across categories, for both nouns and verbs. This suggests that many of the factors that affected naming accuracy for the EN group were still influential in the AD naming performance. This, along with the patients' above-floor performance, also suggests that the semantic system in the AD patients has retained a basic level of knowledge about the concepts tested. This is consistent with results from other tasks performed by this patient group (Aronoff et al., 2006) that demonstrated graceful degradation with nouns. These findings indicate that naming deficits represent a partial rather than complete loss of information about concepts. Thus, the answer to our first question is that verb performance in AD shows graceful degradation that is compatible with a general feature-based framework in terms of the general preservation of unimpaired category structure.

Our second question was whether verb performance in AD is compatible with graceful degradation of connections between features and concepts in a general feature-based framework in terms of error pattern progression. The general feature-based approach predicts that with increased semantic damage, the dominant error type will shift from contrast coordinate errors to super-ordinate errors to cross-category errors, and finally to "do not know" errors (Hodges et al., 1995). We found that, across nouns and verbs, there was a shift in error types in the predicted direction when comparing the EN group to the AD group, and when comparing high performing AD patients to low performing AD patients. Our results extend previous reports of error pattern distribution for nouns (e.g., Hodges et al., 1995) to verbs and therefore indicate that the semantic representation of both concrete nouns and imageable verbs can be explained on the basis of distributed feature-based representations. Thus, the answer to our second question is that error pattern progression with both nouns and verbs is indeed compatible with a general feature-based framework.

Our third and final question was whether patterns of noun and verb domain impairments would support the sensory-functional models of Bird et al. (2000), and Parris and Weekes (2001), and/or the feature inter-correlation models of Gonnerman et al. (1997) or Tyler and Moss (2001). As a group, the patients appeared more impaired on living nouns and instrument verbs, but did not show strong selective impairments with verbs vs. nouns. This finding appears to argue against the claims of Bird et al. (2000), who argued for an association between verbs and non-living nouns, and Parris and Weekes (2001) who argued for an association between instrument verbs and nouns. However, in contrast to the mean group comparisons, the results of the correlational analyses showed patterns compatible with the predictions of both these models. In line with Bird, Howard, and Franklin's (2000) model, better accuracy with nouns relative to verbs was associated with better accuracy with living relative to non-living nouns, and in line with Parris and Weeks's (2001) model, better noun accuracy was associated with better accuracy with instrument verbs than with manner verbs. Although these data are compatible with the models of Bird et al. (2000) and of Parris and Weeks (2001), one aspect of our data is not compatible with these approaches: if manner verbs do indeed rely on sensory features more than instrument verbs (Marshall, Chiat, et al., 1996) then manner verbs should have patterned with living nouns more than instrument verbs, but they did not.

According to theories that emphasize feature inter-correlation, disease progression should have a predictable and differential effect on domain-specific deficits. According to Gonnerman et al. (1997), because the representation of living nouns relies on more inter-correlated features than the representation of non-living nouns, small amounts of damage should lead to a mild domain-specific impairment with non-living nouns whereas large amounts of damage should lead to a pronounced domain-specific impairment with living nouns. The AD patients in our study showed domain-specific deficits for living nouns as a group, as well as a progressive domain-specific deficit for living nouns that was associated with overall decline in noun accuracy. Our findings therefore support the Gonnerman et al. model. Our findings provide strong evidence against Moss, Tyler, and Jennings' (1997) claim that, because distinguishing features tend to be part of inter-correlated feature clusters more often in the representation of non-living nouns than in the representation of living nouns, small amounts of damage should lead to a mild disproportionate deficit for living nouns but large amount of damage should lead to a strong disproportionate deficit for non-living nouns. In our patient group, there were only two patients who showed a domain-specific impairment for non-living nouns, and both were among the better performing patients, arguing strongly against this theory.

While our data support the role of feature inter-correlation for nouns, we did not find similar support for verbs. Rather than a reflection of underlying differences in feature inter-correlation, we believe that the instrument verb deficit we observed can be explained on the basis of the role object information plays in the semantic representation of different verbs. Specifically, we agree with Parris and Weekes (2001) that verbs vary systematically in the extent to which their semantic representation overlaps with the semantic representations of nouns. However, we disagree with these researchers' emphasis on the distinction between sensory and functional features. Instead, we think that instrument verbs showed greater relation to nouns than manner verbs because object information plays a more important role in the semantic representation of instrument verbs compared to other kinds of verbs, such as the manner verbs we used. Instrumental objects in particular are known to be activated during processing of instrumental verbs (Ferretti, McRae, & Hatherell, 2001; Koenig, Mauner, & Bienvenue, 2003; Sussman, 2006), suggesting that information about objects may be necessary for normal processing of these verbs.

In sum, our results are generally compatible with both sensory-functional and inter-correlated featural models, but only some of these models make the correct predictions. For nouns, our results support the inter-correlated featural model of Gonnerman et al. (1997) but not Moss, Tyler, and Jennings' (1997) model. Although for nouns, our results are also compatible with sensory-functional models, this distinction has been criticized in the recent literature (Caramazza & Shelton, 1998; Cree & McRae, 2003; Shelton & Caramazza, 1999, 2001). We therefore believe that an inter-correlated feature model is most likely to be correct.

5. Conclusion

We found strong evidence that the semantic system is governed by an underlying featural system that operates similarly but not identically, for noun and verb representation. Widespread damage to this system, as is the case in Alzheimer's disease, is detectable across the entire semantic system, along with selective and related deficits to specific categories for both nouns and verbs. For nouns, the faster degradation of living compared to non-living nouns is compatible with explanations that emphasize feature inter-correlation. For verbs, we propose that the faster degradation of instrument compared to manner naming is the result of the double requirement of object and action knowledge for instrument verb naming.

Acknowledgments

This research was supported by NIH grant RO1 AG-11774. Alison Flipse and Mariko Taki provided invaluable help in stimuli preparation, testing, and data coding. We thank the participants and their families for their generous contribution of time and effort. Portions of this work were presented at the annual meetings of the Academy of Aphasia (Vienna, Austria, October 2003) and the Cognitive Science Society (Chicago, August 2004). Some aspects of the noun naming data were also reported in Aronoff et al. (2006) but these data are presented and analyzed here at a greater level of detail.

Appendix A. Noun stimulus list

Living	
Domestic animals	Duck, Sheep, Goose, Dog, Cow, Horse, Donkey, Cat, Goat, Pig, Chicken, Camel
Zoo animals	Zebra, Rhinoceros, Walrus, Elephant, Giraffe, Gorilla, Kangaroo, Lion, Monkey, Penguin, Leopard, Tiger
Local wildlife	Moose, Fox, Bear, Mouse, Rabbit, Raccoon, Skunk, Squirrel, Frog, Deer, Beaver, Bird
Insects	Mosquito, Scorpion, Worm, Ant, Bee, Beetle, Butterfly, Caterpillar, Fly, Grasshopper, Moth, Spider
Vegetable	Asparagus, Cabbage, Garlic, Carrot, Lettuce, Celery, Corn, Potato, Onion, Pepper, Pea, Pumpkin
Fruit	Pineapple, Watermelon, Plum, Apple, Banana, Cherry, Grapes, Lemon, Orange, Pear, Peach, Strawberry
Non-living	
Carpenter's tools	Screwdriver, Ladder, Drill, Axe, Chisel, Nail, Hammer, Pliers, Saw, Screw, Vise, Wrench
Kitchen items	Spatula, Stove, Mixer, Pitcher, Cup, Broom, Frying pan, Kettle, Pot, Rolling pin, Bowl, Toaster
Clothing	Coat, Suit, Apron, Vest, Boot, Cap, Necklace, Glove, Hat, Ring, Jacket, Mitten
Musical instruments	Xylophone, Harpsichord, Clarinet, Accordion, Drum, Flute, French horn, Guitar, Harp, Piano, Trumpet, Violin
Vehicles	Scooter, Tractor, Sled, Airplane, Bicycle, Roller-skate, Helicopter, Motorcycle, Sailboat, Canoe, Ship, Truck
Toys	Rattle, Dice, Tricycle, Dart, Balloon, Wagon, Kite, Swing, Top, Football, Blocks, Baseball bat

Appendix B. Verb stimulus list

Manner	
Nonverbal expression	Coughing, Crying, Frowning, Laughing, Panting, Sneezing, Whistling, Yawning
Communication	Confessing, Preaching, Screaming, Singing, Teaching, Warning, Whispering, Yelling
Spatial configuration	Balancing, Bending, Bowing, Hanging, Kneeling, Leaning, Lying, Squatting
Manner of motion	Bouncing, Climbing, Crawling, Floating, Hurdling, Jumping, Marching, Tiptoeing
Social interaction	Boxing, Fighting, Hugging, Kissing, Marrying, Petting, Playing, Wrestling
Ingestion	Breastfeeding, Drinking, Eating, Feeding, Licking, Nibbling, Sipping, Sucking
Instrument	
Grooming and body care	Bathing, Brushing, Combing, Filing, Flossing, Shaving, Showering, Washing, Drying
Vehicle motion	Driving, Flying, Ice-skating, Parachuting, Roller-skating, Rowing, Sailing, Skiing
Building	Arranging, Blowing, Cutting, Grinding, Hammering, Knitting, Sculpting, Sewing
Eating	Baking, Cooking, Frying, Mixing, Pouring, Rolling, Toasting, Tossing
House	Dusting, Ironing, Mopping, Raking, Scraping, Shoveling, Sweeping, Vacuuming
Combining and attaching	Buttoning, Chaining, Clamping, Locking, Pasting, Screwing, Stapling, Taping

Note: The entire set of stimuli and rating can be obtained from the first author.

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