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Automatic semantic priming of nouns and verbs in patients with Alzheimer's disease

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Abstract—The status of semantic representations of nouns (concrete and abstract) and verbs (motion and non-motion) was investigated in patients with Alzheimer's disease (AD). Nouns and verbs have been argued to activate different neural substrates, given the selective difficulties reported for one or the other grammatical class in patients with focal lesions. Additionally, category-specific deficits have been reported for either abstract or concrete words, often in patients with bilateral neuropathology. We looked for these types of dissociations in patients with AD in a semantic priming experiment using a pronunciation task and a short stimulus onset asynchrony.

The normal control subjects demonstrated automatic activation for both concrete nouns and motion verbs. The AD patients, however, demonstrated priming effects for concrete nouns, but not for motion verbs. This dissociation between concrete nouns and motion verbs found for the AD patients is discussed in terms of differences in the nature of semantic representations involving multiple physical and functional attributes in the case of concrete nouns, but only motion attributes in the case of motion verbs. Moreover, the typical distribution of neuropathology associated with AD may put motion verbs at risk, particularly given the neuroanatomical considerations suggested by recent positron emission tomography (PET) studies. Published by Elsevier Science Ltd

Key Words: semantic memory; aphasia; category-specific deficits; language.

Introduction

Studies on the effects of brain damage on language have led to some important insights about the neural organization of lexical and semantic knowledge. Perhaps best known are category-specific disorders, in which, for example, one patient may have trouble recognizing and naming pictures of living things relative to man-made objects, whereas another patient may have selective difficulty with man-made objects [61]. Other types of dissociations have also been reported, such as that for nouns and verbs. When production and comprehension abilities for nouns and verbs have been compared, patients who demonstrate more difficulty with nouns relative to verbs are typically fluent aphasics with posterior, temporoparietal lesions. In contrast, patients who are reportedly worse on verbs than nouns are most often non-fluent aphasics with lesions affecting the left frontal lobe [6, 14, 15, 37, 38, 66, 67]. This double dissociation supports the notion that nouns and verbs have different neural substrates [10, 13, 19].

Another example of selective loss of semantic knowledge resulting from brain damage concerns the concrete–abstract dimension. Here, concreteness refers to the extent to which a word's referent can be experienced by the senses (see [50] for a review). Evidence suggesting that concrete words (e.g., tiger, oven, lime) and abstract words (e.g., skill, freedom, knowledge) are represented differently in the brain comes from patients who have either specific difficulties with abstract words, relative to concrete words [55, 60, 61], or show the reverse pattern of impairment [61].

In the past, category-specific impairments have been reported for patients from several populations with a variety of etiologies, who are tested using different kinds of production and comprehension tasks. These uncontrolled variations across studies are not optimal for using category-specific disorders to further our understanding about ways in which semantic knowledge is represented in the brain. To remedy this, in the present study, we used the *same* experimental paradigm to look for dissociations along the noun–verb dimension and the concrete–abstract dimension, in *one* population, a group of patients with Alzheimer's disease (AD). Specifically, we examined

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the effects of AD on the semantic representations of nouns (concrete vs abstract) and verbs (motion vs non-motion).

The examination of semantic knowledge in patients with AD is of interest given the numerous reports of its disruption, even in early stages of the disease. Semantic errors on picture naming tasks, impaired knowledge about the attributes and characteristics of objects, and greater difficulty retrieving words to semantic category cues than to initial letter cues [4, 5, 11, 21, 24, 26, 29, 32, 41, 46] all suggest that AD produces degraded semantic representations (see [11, 25, 29, 30], but for an alternative view see [28, 42, 47]). Generally, these tasks require subjects to produce concrete nouns or probe knowledge about concrete nouns. As a result, little is known about these patients' ability to generate and comprehend abstract nouns. One major difference between abstract and concrete nouns is that the referents for concrete nouns are directly perceived through the senses, whereas abstract words are not [50]. The present study investigated whether the semantic representations of abstract words, which, by definition, lack attributes that can be perceived through sensory channels (e.g., shape, size, color, function), are as vulnerable as concrete words to the effects of AD.

Given the dissociations reported for nouns and verbs, we were also interested in looking at the effects of AD on grammatical class. Because we were looking for dissociations between nouns and verbs, we tested a category of verbs that are unambiguous with respect to grammatical class. Although there are many different verb categories [39, 40], action verbs (e.g., run, jump, dive, fly) are routinely used in studies looking at the effects of brain damage on semantic knowledge because they are easily depicted (e.g., The Action Naming Test [49]). Action verbs, however, were excluded from the present study because they are ambiguous with respect to grammatical class, as they can also be used as nouns, depending on the context. To avoid these problems, we selected the motion verb category on the basis of a semantic feature analysis done by George Miller [39]. He defined motion verbs as words for indicating how an object that is at one place in time comes to be at another place at some subsequent time (e.g., rotate, send, shake, carry). Motion verbs are similar to the concrete nouns in terms of their referents being perceived through sensory modalities (i.e. the visual system). The motion verbs chosen form a group on the basis of one common feature, motion. In addition, we tested grammatically unambiguous, non-motion verbs to evaluate whether any impairment in verb processing caused by AD would apply to other types of verbs, particularly verbs whose referents are not necessarily perceived through the senses. The non-motion verbs were selected such that they did not form a group on the basis of any sensorimotor features, and thus are not to be considered constituents of a perceptually-based semantic category.

Because we set out to assess the integrity of semantic knowledge in patients with AD, we used an on-line semantic priming paradigm. Typically, past studies investigating semantic deficits in patients with AD assessed their performance using off-line tasks with substantial attentional and retrieval demands. As a result, it has been argued that poor performance on these tasks reflects deficits in attentional and other cognitive processes necessary to complete these tasks, rather than deficient semantic processes *per se* [42, 47]. The on-line measure in the present study was implemented to circumvent potential task-related confounds involving attentional demands. In the semantic priming paradigm, a trial consists of two words presented consecutively, and the subject's task is to read the first word (referred to as the prime word) silently and then say the second (referred to as the target word) out loud as quickly as possible. The data of interest are how fast subjects say the target word as a function of whether the prime word that precedes it is related or unrelated to the target word. The semantic priming paradigm is particularly sensitive to the mechanism of automatic activation between related semantic representations. Presumably, the semantic system is organized such that upon presentation of a priming word (e.g., tiger), related semantic representations are automatically activated (e.g., lion) [12] as a result of the activation of attributes shared among the related semantic representations [30, 34]. Thus, the reaction time (RT) to pronounce a related target word is significantly reduced, relative to the RT measured in the unrelated condition, in which the target word (e.g., lion) is preceded by an unrelated prime word (e.g., oven). The reduction in RT in the related condition, compared to the unrelated condition, is called a priming effect.

Automatic activation between related semantic representations is believed to occur without the allocation of attentional resources and without strategic control [51]. To isolate the effects of automatic activation from attention-driven, strategic priming effects, we used a low proportion of related words in a test block, so that subjects would not be motivated to use the prime word to generate expectancies for a related target word [16, 45]. In addition, we used a short time interval (250 msec), between the onsets of the prime and target words, referred to as the stimulus onset asynchrony (SOA). A short SOA is necessary because automatic activation is fast acting, in that it tends to dissipate in approximately half a second in the normal population [44]. Moreover, to rule out the occurrence of strategic processing, we included a longer SOA (750 msec). Semantic facilitation at longer SOAs has been found to reflect the presence of attention-driven, controlled processing in the normal elderly population [2, 57], as well as in the normal young adult population [16]. Thus, given our list composition, we would not expect to find semantic priming at the longer SOA. In summary, we set out to obtain automatic semantic priming effects at the short SOA, for four types of stimuli (concrete and abstract nouns, motion and non-motion verbs).

Methods

Subjects

Twenty AD subjects (10 females and 10 males) and 16 normal control (NC) subjects (eight males and eight females) were tested (see Table 1 for background information on the 16 NC subjects and the 16 AD subjects from whom data are reported). The AD patients were diagnosed with probable AD in accordance with criteria set forth by the NINCDS-ADRDA Work Group [36]. Each patient was diagnosed on the basis of medical history, neuroimaging and lab tests to rule out other contributing neurological illness. Normal elderly subjects were in good health without history of neurological disease or psychiatric illness. The AD patients and NC subjects did not differ significantly on age or years of education. As expected, the AD patients were significantly worse ($P < 0.01$) than NC subjects on the Dementia Rating Scale [35], and had difficulty naming pictures of objects on the Boston Naming Test [20]. Nevertheless, the AD subjects' word reading skill, including reading irregular words, was well preserved, based on their performance on the American Version of the Nelson Adult Reading Test [22].

Materials

A base stimulus list of 80 related critical stimulus pairs was created. These 80 related pairs consisted of the following subsets: 20 motion verb pairs, 20 non-motion verb pairs, 20 concrete noun pairs and 20 abstract noun pairs (see Appendix). Semantically unrelated pairs were created by re-pairing the related prime–target pairs within these four classes, without changing the designation of prime or target. The motion verbs were taken from Miller [39] and paired on the basis of meaning. The critical stimuli were unambiguous with respect to grammatical class, in that the nouns did not have an alternative verb meaning and the verbs did not have an alternative noun meaning. The prime–target relationship of most of the critical pairs was semantic, with the few semantic plus associative pairs distributed evenly across stimulus types.

To confirm the relatedness between prime and target words, relatedness ratings were collected from 25 college-aged, native speakers of English. The related pairs were rated as 3.6, 3.7, 3.5 and 3.9 (out of a maximum of 5) for motion verbs, non-motion verbs, concrete nouns and abstract nouns, respectively. In addition, 20 subjects rated each critical target noun for concreteness. The mean concreteness rating for concrete nouns was high (6.6; maximum = 7), whereas the mean concreteness rating for abstract nouns was quite low (2.4).

In addition, critical noun and verb targets were matched for length and frequency across the four stimulus types as closely as possible, given the overriding criterion of using only unambiguous noun and verb stimuli. Although in word frequency counts (e.g., [18]) verb frequency ratings are broken down into the various verb conjugations, gerunds (nouns) are not separated from the progressive tense (verbs). Thus, the verb ratings used here were the sum of the base form rating, third person singular rating and the past tense rating, excluding the ratings for the progressive/gerund forms. Given this constraint, the four types of targets (concrete and abstract nouns, motion and non-motion verbs) were matched on frequency [$F(3,76) = 1.11$].

The short SOA (250 msec) and the long SOA (750 msec) were intermixed randomly within each test block, as were the related and unrelated prime conditions and the four word types. Each target word appeared only once during each test block. This necessitated the creation of four versions of the stimulus list so that each target word could appear in each of the two SOA conditions (short, long) and in each of the two priming conditions (related, unrelated), across the four versions. We used a within-subjects design, such that each subject saw each of the four versions of the stimulus list once.

Each version of the stimulus list was composed of 80 (40 related and 40 unrelated) critical trials and the 64 unrelated filler trials, for a total of 144 trials. The unrelated filler trials were included to lower the relatedness proportion to 0.27, thus minimizing strategic processing [16, 17, 45]. Thirty-two noun–noun and 32 verb–verb unrelated filler pairs were created by re-pairing primes and targets from a base list of related word pairs. The filler word pairs were repeated across the four versions, as were the critical pairs, but were re-paired in novel prime–target pairs for each version. Repeating the filler words across lists was done so that the repeated, critical targets would not stand out in a background of unrepeated filler targets.

Table 1. Demographic and clinical data [mean (S.D.)] for Alzheimer's disease and normal control subjects

	AD (n = 16)	AC (n = 16)
Age (years)	73 (8.0)	74 (5.0)
Education (years)	14 (3.1)	16 (2.1)
Dementia Rating Scale	118* (11.7)	142* (2.1)
Nelson Adult Reading Test, American version	111 (11.0)	N/A
Boston Naming Test	44 (7.9)	N/A

*$P < 0.01$.

Procedure

All stimuli were presented in lower case letters on a Macintosh IIcx. Voice onset time was recorded in milliseconds from the onset of the target word (Gerbrands voice operated relay, model GT1341). A pronunciation task was used with primes and targets presented consecutively. A fixation cross appeared in the center of the screen as a warning signal that the trial was about to begin. Primes and targets were presented at fixation. Subjects were instructed to read the prime words silently and to read the target words aloud as quickly as possible. The target word, but not the prime word, appeared in a box to cue overt pronunciation. The following presentation parameters were set: fixation cross for 1500 msec, prime duration of 150 msec, interstimulus interval of either 100 or 600 msec depending on SOA condition, target duration of 1000 msec or until a response was recorded, whichever came first. The intertrial interval was 2000 msec.

Twenty practice trials were given before the test trials. The order of presentation of the four test blocks was counterbalanced across subjects. Generally, the test blocks were administered with either a few hours or several days between sessions, depending on the subject's availability. A single test block lasted approximately 12 min.

Results

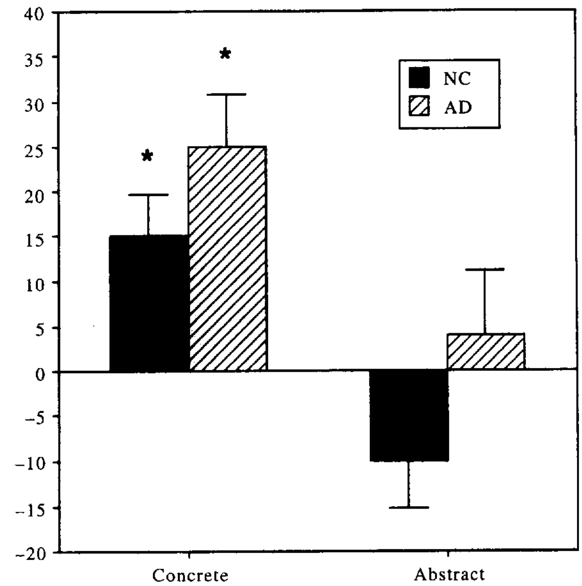
Data from four AD patients were excluded from the analyses. Two of these subjects could not inhibit reading the prime word aloud and had difficulty remembering the task instructions. The other two subjects were unable to read the target word aloud consistently within the interval during which responses were recorded (i.e. 37% and 44%

late responses versus a mean of 5% for the remaining 16 AD subjects). Error rates were not analysed because they were low for the AD patients and virtually zero for the NC subjects. Separate analyses of variance (ANOVAs) were performed on the means of the median RTs for the nouns and verbs.

Nouns

A four-factor ANOVA, Group (NC, AD) × SOA (long, short) × Type (concrete, abstract) × Prime (related, unrelated), was conducted on the noun data. Significant main effects (all at $P < 0.001$) were found for Group [$F(1,30) = 14.0$], SOA [$F(1,30) = 50.26$], Type [$F(1,30) = 25.63$] and Prime [$F(1,30) = 19.51$]. Respectively, these effects reflected that RTs were faster for NC than for AD subjects, for the long than for the short SOA, for concrete than for abstract nouns, and for related than for unrelated targets. Of greater interest was the significant Type × Prime interaction [$F(1,30) = 14.04$; $P < 0.001$], which did not interact with Group [$F(1,30) < 1$]. A least significant difference (LSD) test on the priming effects from the Type × Prime interaction (using the mean square error from the Type × Prime interaction, $MSe = 278.99$) revealed a significant priming effect for concrete nouns ($P < 0.001$), but not for abstract nouns.

The mean RTs for concrete and abstract nouns separated by subject groups and SOAs are presented in Table 2. As can be seen, the priming effects for the concrete nouns were greater at the short SOA than at the long SOA for both groups. In addition, neither the NC nor the AD subjects showed priming for the abstract nouns at either SOA. These observations were supported by an LSD test (using the MSe from the SOA × Type × Prime × Group interaction, $MSe = 412.67$), which revealed significant priming effects ($P < 0.05$) for the concrete nouns only at the short SOA for both NC and AD subjects (see Fig. 1). No other comparisons were significant.



*P<0.05, two-tailed

Fig. 1. Mean priming effects, at the short SOA, for the normal control subjects (NC) and Alzheimer's patients (AD) for concrete and abstract nouns.

Verbs

A four-factor ANOVA, Group × SOA × Type (motion, non-motion) × Prime, was performed on the RTs. Consistent with the analysis on nouns, significant main effects (all $P < 0.001$) of Group [$F(1,30) = 14.12$], SOA [$F(1,30) = 44.40$] and Type [$F(1,30) = 14.87$] were found. However, in contrast to the noun data, the main effect of Prime was not significant [$F(1,30) = 1.59$], whereas the Group × Prime interaction was significant [$F(1,30) = 4.89$; $P < 0.05$]. An LSD test (using the MSe from the Group × Prime interaction, $MSe = 277.36$) revealed that the NC subjects demonstrated priming for verbs ($P < 0.05$), whereas the AD patients did not.

Table 3 displays the mean RTs to verbs for the two subject groups, at each SOA. Although the above analyses indicated that the NC subjects showed significant priming for verbs overall, inspection of these data suggests that priming was limited to motion verbs, and that

Table 2. Mean reaction times for nouns (in msec)

	Short SOA		Long SOA	
	Concrete	Abstract	Concrete	Abstract
	NC subjects			
Unrelated	566	567	541	548
Related	551	577	528	544
Priming effects	15*	−10	13	4
	AD subjects			
Unrelated	668	681	629	634
Related	643	677	621	633
Priming effects	25*	4	8	1

*$P < 0.05$.

Table 3. Mean reaction times for verbs (in msec)

	Short SOA		Long SOA	
	Motion	Non-motion	Motion	Non-motion
	NC subjects			
Unrelated	570	572	543	545
Related	555	570	537	539
Priming effects	15*	2	6	6
	AD subjects			
Unrelated	666	677	625	632
Related	663	685	625	634
Priming effects	3	−8	0	−2

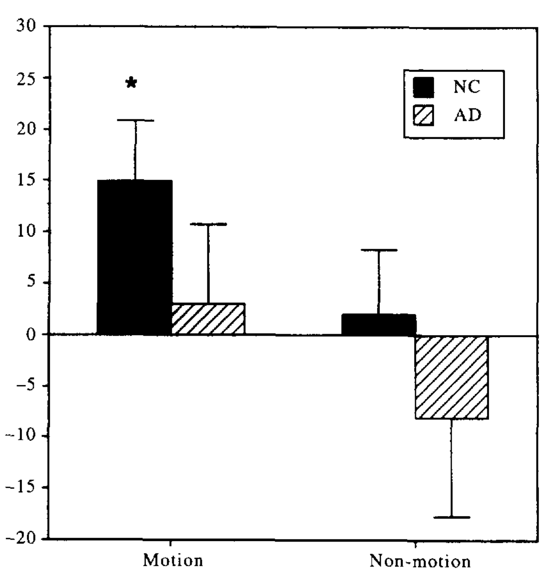
*$P = 0.06$.

this effect was largest at the short SOA. In contrast, the AD patients clearly failed to demonstrate priming for either verb type at either the long or the short SOA. To confirm these observations, an LSD test was performed on the priming effects using the *MSe* from the SOA × Type × Prime × Group interaction ($MSe = 493.99$). The only notable priming effect was for the NC subjects, for motion verbs at the short SOA ($P = 0.06$; see Fig. 2).

Discussion

Several findings emerged from this study. First, when they occurred, significant priming effects were found at the short (250 msec), but not the long (750 msec) SOA. This suggests that the design constraints were successful in eliciting automatic activation of semantic representations, and in preventing the utilization of attention-driven, strategic processes that produce priming at longer SOAs. Second, neither the NC subjects nor the AD patients demonstrated priming for the abstract nouns or the non-motion verb pairs. Third, and most importantly, whereas the NC subjects demonstrated priming for both concrete noun pairs and the motion verb pairs, the AD subjects showed priming only for concrete nouns. We will first briefly comment on the failure to observe priming for abstract nouns and non-motion verbs and then discuss the dissociation between concrete nouns and motion verbs in AD.

Automatic activation of abstract words using the semantic priming paradigm has not been studied extensively. Nevertheless, there are reports in the literature of significant semantic facilitation with abstract word pairs [7],



**P*=0.06, two-tailed

Fig. 2. Mean priming effects, at the short SOA, for the normal control subjects (NC) and Alzheimer's patients (AD) for motion and non-motion verbs.

although the priming effect tends to be weaker compared to priming with concrete nouns [59]. Within the context of these experiments, the failure to observe significant priming of abstract words in the present study is not clear, and could reflect differences in the paradigms and/or materials. One noteworthy difference between our study and previous reports is that while we restricted our abstract words to a single grammatical class (nouns), the other studies did not. Grammatical class was not examined *per se*, and thus ambiguity was not controlled for [7]. One possibility is that words used as one or more parts of speech have more elaborate semantic representations and thus are more likely to produce priming as compared to words that are limited to only one grammatical class. Regardless of these differences in findings across studies, we clearly cannot attribute the absence of priming for AD subjects for a particular kind of item to a semantic deficit when that type of item does not yield priming for the NC group. Thus, the AD subjects' failure to show priming for the abstract nouns in the present study is inconclusive. The same point holds for the non-motion verbs.

One explanation for the reliable, robust priming found for concrete nouns, relative to the unreliable priming for abstract nouns, concerns the nature of the semantic representations of concrete nouns. Their semantic representation entails attribute knowledge, consisting of physical and functional attributes (physical referring to shape, size and color, functional referring to ways in which the object functions or is used). Presumably, physical and functional attributes intrinsic to concrete nouns are bound to create a semantic representation through sensorimotor experience with these words and their concrete referents. The physical and functional attributes for a concrete word may be elaborated into information from each modality that is weighted according to the relative saliency of each attribute. Thus, concrete words are believed to activate a distributed neural network involving multiple areas that process the attributes defining those objects [1, 50, 54, 61, 62]. However, little is known about the semantic representations for abstract words, except that physical and functional attributes do not seem to be particularly relevant to their semantic specification. The essential point here is that semantic priming for concrete nouns may be mediated by multiple attributes represented in a distributed network in the brain.

The important finding in this study concerns the dissociation between concrete nouns and motion verbs for the AD group. To understand this dissociation, consider the degree of overlap in semantic attributes between the prime and target nouns versus verbs. Given that we used a semantic priming paradigm to examine automatic activation between pairs of related semantic representations, one might say that in essence we tested the activation of *shared* attributes. The related motion verb pairs were selected on the basis of a single shared semantic feature (motion and its properties) and therefore may activate a more focal representation than the related concrete noun pairs, which share multiple physical and functional attributes. Because the motion verb pairs share fewer semantic attributes than the concrete noun pairs, their priming effects may be more vulnerable to the damage caused by AD. In the case of the concrete nouns, it seems that enough of the multiple shared attributes were spared to mediate semantic priming. In contrast, the relatively fewer shared attributes between the motion verb prime–target pairs were not sufficiently spared to mediate semantic priming.

Support for the notion that motion verbs may be vulnerable to the effects of AD comes from the studies using positron emission tomography (PET) scanning to identify areas of activation for different kinds of words. A recent PET study from our laboratory [33], in which normal subjects generated verbs to either picture or word stimuli, suggests that motion knowledge may be represented in an area particularly vulnerable to the effects of AD. Activation was observed in the posterior portion of the middle temporal gyrus, in addition to several other areas of activation. Activation of the middle temporal gyrus was also found in other PET studies that required subjects to generate verbs [52, 65]. Because of the close proximity of this posterior area to the areas known to mediate motion perception [63], we argued that knowledge about object motion may be represented in this region. This temporal area is at high risk for damage from AD* [8, 27, 31]. Thus, knowledge about motion verbs may be particularly vulnerable as well. Interestingly, there is evidence that AD patients have a selective deficit for motion perception relative to motion detection, suggesting that the regions involved with motion perception may also be compromised [56, 58].

Another source of evidence that motion verbs may not be resistant to semantic deterioration resulting from AD comes from a series of recent studies by Grossman and colleagues [23, 53, 64]. These investigators found that, across a variety of tasks, such as confrontation naming, comprehension and word–picture matching tasks, AD patients performed consistently worse with verbs relative to nouns. They argued that verbs were more impaired than nouns because the semantic representations for nouns are richer than verbs to the extent that attribute knowledge (e.g., physical and functional attributes) is redundant between nouns and is organized in a hierarchy consisting of several layers of information (e.g., subordinate, coordinate and superordinate). Because semantic priming depends on the semantic features shared by the prime and target words, clearly, the more redundant and numerous shared attributes there are, the more likely priming effects will be obtained, as in the case of concrete nouns in the present study.

The dissociation of aberrant performance with motion verbs relative to concrete nouns in the AD subjects points to a processing stream for verbs that is distinct from that for nouns. The notion that nouns and verbs are represented differently is consistent with the reports of patients with focal lesions resulting from cerebrovascular accidents, or strokes, who suffer from residual chronic aphasia. However, there is a potential conflict with these studies on stroke patients who exhibit noun–verb dissociations and the data presented here. As discussed previously, those patients who show worse performance with verbs than nouns usually have lesions involving the left frontal lobe. AD patients, however, commonly have greater involvement of posterior temporal and parietal regions than of the frontal cortex. This conflict may be resolved when the difference in materials used in the studies investigating stroke patients and the materials used in the present study is considered. Typically, action verbs are used to test aphasic patients because they are easily depicted in line drawings. In terms of testing verb production, the Action Naming Test [49], consisting of action verbs, is routinely used. In terms of assessing verb comprehension, reversible passive sentences with action verbs are often used, as in the sentence: "The doctor was kicked by the man". Commonly, action verbs, such as chase, kick and hit, are used in these sentences. It may be that action verbs are represented more heavily in anterior areas because of the proximity of these areas to frontal motor cortices, which may mediate action† [13, 15, 19]. Indeed, if this were true, then AD patients, who presumably have predominantly posterior pathology, are likely to perform better with action verbs than motion verbs and may even demonstrate priming effects for action verbs using the procedures in our study. In light of the previously discussed PET data, it is plausible that the posterior pathology associated with AD may impair knowledge about motion, including motion verbs, as opposed to the relatively more anteriorly represented action verbs. Currently, research is underway to investigate dissociations between action and motion verbs in AD patients, in an attempt to demonstrate the fractionation of the semantic category of verbs.

Finally, an interesting finding in the present study is that priming effects for the concrete nouns were not hypernormal. Hyperpriming has been found in many studies on AD patients using the semantic priming paradigm [3, 11, 30, 43], and has been linked to either semantic

* Martin *et al.* [31] demonstrated that although subgroups of AD patients exist on the basis of PET scans and neuropsychological tests, all of the patients with language deficits had hypometabolism in either the left temporal region or bilaterally in temporoparietal regions.

† Many patients with the verb deficit associated with anterior lesions also present with the disorder referred to as agrammatism, characterized by impaired production and comprehension of syntactic structure beyond simple active sentences [37]. Generating syntactic structure is thought to hinge on the accessibility of the main verb, which appears to be defective in patients with lesions involving frontal areas. However, conflicting data have been reported recently. There are some patients with posterior lesions who show adequate sentence structure, but worse verb production relative to noun production [6, 9, 10].

degradation [11, 30] or attentional deficits [42, 47, 48]. However, our study differs from the studies in which hyperpriming effects have been found in that a low relatedness proportion and a short SOA were used in order to isolate the effects of automatic activation from attention-driven, controlled processing. Moreover, the use of pictures [30], rather than words as in the present study, is another crucial difference in design that potentially contributed to the difference in results. The only study to date, that we are aware of, implementing similar constraints and examining word recognition using concrete nouns, was done by Ober *et al.* [48]. These investigators found that the semantic priming effects obtained for the AD patients did not differ from those obtained for the normal control subjects. The results found by Ober *et al.* are consistent with those found in the present study for the concrete nouns. These two studies (the present study and Ober *et al.*'s study) suggest that automatic activation may be normal in its onset in patients with AD, but it is not yet clear what drives the activation to become hypernormal, as is found with high relatedness proportions at longer SOAs (see [30] for a model of how degraded semantic representations could result in hyperpriming). Clearly, the AD patients have difficulties with concrete nouns in spontaneous speech as well as in object naming and verbal fluency tasks. Our data do not directly address this issue, but they do suggest that the semantic representations for concrete nouns are sufficiently distributed to mediate semantic priming, whereas the semantic representations for motion verbs are not.

In conclusion, our findings indicate a dissociation between concrete nouns and motion verbs for patients with AD. We believe that this dissociation points to a critical difference in the neuroanatomical representation of the attributes that define items within these categories. The difference in neuroanatomical organization may reflect a widely distributed semantic representation for concrete nouns, in contrast to a more focal representation for motion verbs. As a result, the semantic representations of motion verbs may be more vulnerable to the effects of AD than the more widely distributed representations of concrete nouns.

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Appendix: Critical stimulus pairs

	Concrete nouns	Astract nouns	Motion verbs	Non-motion verbs
1	inn–hotel	freedom–liberty	lengthen–extend	see–hear
2	gold–silver	story–legend	go–come	donate–give
3	university–college	soul–spirit	pursue–follow	excite–arouse
4	tiger–lion	guidance–advice	revolve–rotate	appear–seem
5	bee–honey	contempt–wrath	carry–bring	disregard–ignore
6	cafe–restaurant	morality–ethics	meander–wander	obtain–get
7	lime–lemon	defense–protection	depart–arrive	speak–listen
8	office–desk	talent–skill	expand–grow	multiply–divide
9	cent–penny	catastrophe–disaster	tremble–shake	whine-complain
10	sky–sun	paradise–heaven	soak–absorb	predict-anticipate
11	cloth–fabric	enjoyment–pleasure	deliver–send	convince–persuade
12	turnpike–highway	enemy–foe	recede–withdraw	add–subtract
13	sheep–wool	error–mistake	penetrate–enter	prohibit–prevent
14	banana–fruit	fortune–wealth	gather–collect	instruct–educate
15	beer–wine	knowledge–wisdom	ramble–roam	furnish–provide
16	oven–stove	song–music	detach–remove	inspect–examine
17	mud–dirt	idea–concept	open–shut	rely–depend
18	cheese–cracker	security–safety	proceed–continue	demonstrate–prove
19	butterfly–moth	haven–refuge	widen–broaden	select–choose
20	street–avenue	magic–voodoo	heave–hurl	amuse–entertain