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VERB ACQUISITION AND REPRESENTATION IN ALZHEIMER'S DISEASE

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Abstract

We examined the implicit acquisition and mental representation of a novel verb in patients with probable Alzheimer's disease (AD). Patients were exposed to the new verb in a naturalistic manner as part of a simple picture story. We probed grammatical, semantic and thematic matrix knowledge of the verb soon after presentation and again one week later. We found partial verb acquisition that was retained over one week. AD patients did not differ from controls in their acquisition and retention of a new verb's major grammatical subcategory, although they acquired little of its semantic properties and displayed minimal acquisition of the new word's thematic matrix. Moreover, AD patients appeared to maintain their acquired grammatical knowledge over one week. We discuss the implications of these findings from several perspectives, including the modularity of the language processing system, the relationship between episodic memory and semantic memory, and the role of the preserved implicit memory system in AD patients' partially successful lexical acquisition.

Keywords

Alzheimer's; learning; semantic; grammar

INTRODUCTION

Patients with probable Alzheimer's disease (AD) have significant difficulty with single words. Most work focuses on naming and understanding nouns and the corresponding objects. It is unclear whether observed deficits generalize to other word classes such as verbs. In the present study, we examine the implicit acquisition and mental representation of a new verb.

Several reports describe worse performance with verbs than nouns in AD. This includes visual confrontation naming difficulty with verbs (Robinson, Grossman, White-Devine, & D'Esposito, 1996), a deficit with verb-picture matching (White-Devine et al., 1996), and an impairment selecting the best of four verbs related to a description or a video (Yi, Moore, & Grossman, 2006). Although there are occasional exceptions to this relative difficulty with verbs in AD (Fung et al., 2001; Robinson, Rossor, & Cipolotti, 1999), a number of accounts have been forwarded to explain their verb deficit. These focus on the several important ways that verbs differ from nouns. First, a noun is embedded in a well-organized, redundant, and hierarchically structured semantic network, but verbs are part of a poorly structured network

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with impoverished hierarchical and lateral relationships (Jackendoff, 1983; Levin, 1993; Miller & Fellbaum, 1991). There are several consequences of this kind of difference. A well organized hierarchical structure appears to provide strong support for compensatory mechanisms as a distributed network for noun meaning degrades during the course of the disease (Rogers et al., 2004), but similar compensation may not be as available to support processing of verbs (Robinson et al., 1996; White-Devine et al., 1996; Yi et al., 2006). Secondly, a verb represents many different types of linguistic information. In addition to its semantic representation, a verb also contains a rich amount of grammatical information. Many verbs thus exhibit a preference for a particular sentence structure. This determines the grammatical characteristics of an utterance containing the verb. Moreover, the preferred sentence structure may have consequences for verb meaning. A verb preferring a sentence complement tends to be associated more with perceptual-cognitive than motion-action meaning, for example (Fisher, Gleitman, & Gleitman, 1991). Thematic matrix knowledge is also represented in a verb. This describes who can do what to whom, and the nature of the associated thematic roles. Some verbs must have an animate agent, for example, and a subset of these verbs does not have a recipient (Gleitman, 1990). Finally, the large burden of diverse knowledge associated with a verb may place a substantial demand on executive resources that is less evident during noun processing.

In the present study, we examine verb representations by teaching AD patients a novel verb. Previous work examining the acquisition of real-world lexical knowledge by amnesics is mixed. The most relevant work comes from reports describing knowledge of the meaning of words that entered the lexicon following the onset of amnesia. Some work describes difficulty acquiring novel vocabulary terms (Gabrieli, Cohen, & Corkin, 1988; Verfaellie, Croce, & Milberg, 1995). However, others observe successful post-morbid acquisition of new words by amnesics (Kitchener, Hodges, & McCarthy, 1998; Westmacott & Moscovitch, 2001; Westmacott & Moscovitch, 2002). Accounts forwarded to explain successful vocabulary acquisition by amnesics include the possibility that the new terms are associated meaningfully with previously acquired words that remain part of the patient's vocabulary despite medial temporal lobe damage (Glisky, Schacter, & Tulving, 1986). Another possible mechanism mediating this learning may be the implicit, non-intentional method by which we generally acquire new vocabulary terms (Graf & Schacter, 1985). It is also possible that some residual episodic memory contributes to successful lexical acquisition. The neural basis for novel vocabulary acquisition may involve cortical mechanisms that do not involve medial temporal lobe structures such as the hippocampus (Westmacott et al., 2001). Even if acquired, knowledge may need to be probed in a particular manner such as with recognition techniques (Verfaellie, Koseff, & Alexander, 2000), and this may reflect that the novel words may be "hyperspecific" or otherwise impoverished in their representation (Grossman, 1987; Schacter, 1985). Computational models consistent with this characterization hypothesize cortically-mediated knowledge acquisition that is fragmented, inflexible, and acquired slowly and only after multiple presentations (McClelland, McNaughton, & O'Reilly, 1995).

A previous study of verb acquisition in AD took advantage of many features associated with the successful post-morbid acquisition of lexical knowledge, such as the use of implicit learning and subsequently probing acquired knowledge with a recognition technique (Grossman, Mickanin, Onishi, Robinson, & D'Esposito, 1997). Moreover, this study adopted a detailed approach that allows simultaneous examination of the broad range of information represented in a verb. As far as we are aware, this is the only study that has assessed the status of non-semantic lexical knowledge that is novel. The report described selective word-learning, consistent with the notion that limited knowledge can be acquired by amnesics. The patients acquired minimal semantic knowledge about the new word, but their judgments of the new verb's grammatical properties did not differ from normal performance.

The present study also examines lexical acquisition, but this differs from our previous work in several important ways. First, while this technique is capable of assessing multiple aspects of a new word, verb thematic matrix was not examined previously. In the present study, we determine if the thematic matrix component of a verb can be acquired, and whether the representation of this knowledge is more closely related to the semantic attributes or the grammatical attributes of a verb by observing whether an impairment in thematic matrix acquisition tracks semantic or grammatical aspects of the new verb. Second, the previous study examined acquisition of a motion verb, but the verb in the present study involves facial expression. Semantic attributes of a novel verb may have been disproportionately compromised in the previous study since the motion component of the action concept underlying the previous novel verb may be impaired in AD (Gilmore, Wenk, Naylor, & Koss, 1994). The present study instead takes advantage of the relatively preserved social and personality attributes in AD, and thus may optimize the likelihood that the meaning of a new verb can be acquired successfully in AD. Third, the grammatical properties of the novel verb in the present study differ from the verb used in previous work. Specifically, the verb in the present study can not be passivized. This constrains the demands placed on the verb's grammatical representation, and this too may optimize lexical acquisition. The present study nevertheless attempts to replicate one of the unique aspects of the previous study by examining the grammatical component of a new word. Finally, unlike our previous study, we observe the maintenance of the new verb's representation over the course of one week. This has important therapeutic implications for patients with AD. The present study teaches the verb in a naturalistic manner similar to that used successfully in the previous experiment. This is important since this naturalistic approach does not involve intentional exposure and explicit memory of a stimulus, that is, an episodic form of memory that is quite impaired in AD. Instead, this naturalistic exposure appears to share many features with implicit memory that is relatively preserved in AD (Balota & Ferraro, 1996; Bondi & Kaszniak, 1991; Monti et al., 1996). It is thus possible that information acquired about the new verb may be maintained over time. Preserved implicit memory has been demonstrated with measures of sensory-perceptual priming such as word-stem completion and word identification, but conceptual priming is said to be limited in AD (Fleischman & Gabrieli, 1998; Fleischman et al., 2005). Our study thus examines the limits of the conceptual priming deficit in AD, and can begin to determine whether this approach has any therapeutic promise for learning real-world knowledge in AD.

We expected AD patients to demonstrate partial acquisition of the new verb – they were expected to learn more about the grammatical properties of the new verb than its semantic features. Much evidence shows that patients with AD have semantic memory difficulty (Grossman et al., 2003a; Hodges, Patterson, Graham, & Dawson, 1996), perhaps due to degraded semantic knowledge (Garrard, Patterson, Watson, & Hodges, 1998; Garrard, Lambon Ralph, Patterson, Pratt, & Hodges, 2005; Silveri, Daniele, Giustolisi, & Gainotti, 1991) or to a deficit in processing semantic representations (Grossman et al., 2003b; Koenig et al., 2007; Koenig & Grossman, 2007). By comparison, assessments of grammar in AD associate difficulty with the working memory component of sentence processing (Grossman & White-Devine, 1998; Waters, Rochon, & Caplan, 1998). If thematic matrix knowledge depends on semantic information, moreover, then we might also see difficulty acquiring this aspect of a verb. To the extent that naturalistic lexical acquisition depends on successful conceptual implicit memory, we also expected to observe some retention of acquired verb knowledge over the course of one week.

METHODS

Subjects

Patients with a diagnosis of AD (n=11) were recruited in the Cognitive Neurology Clinic of the Department of Neurology at the Hospital of the University of Pennsylvania using published consensus criteria (McKhann et al., 1984). Exclusion criteria included evidence of a second neurological condition such as vascular disease, hydrocephalus, or head trauma, a primary psychiatric disorder, sedating medications such as benzodiazepines, or an untreated medical condition affecting cognition such as hypothyroidism. Healthy controls (n=17) were recruited using flyers posted throughout the community as well as spouses of patients not included in this study. Demographic data are summarized in Table 1. T-tests did not reveal significant differences between AD patients and healthy seniors in age at testing [$t(26)=1.10$; ns] or education level [$t(26)=0.68$; ns]. AD patients were significantly impaired cognitively compared to controls, according to the MMSE [$t(23)=4.16$; $p<0.001$]. Performance on other neuropsychological measures, summarized in Table 1, is consistent with the clinical diagnosis of AD. None of these patients had a disorder of social comportment and personality. Informed consent was obtained for all research participants under a protocol approved by the University of Pennsylvania Institutional Review Board.

Materials

We taught patients the verb “lour”, a very-low-frequency English word expected to be unfamiliar to most subjects. We chose to use a real English verb rather than a pseudoword in order to avoid potentially anomalous treatment of the word due to unknown phonotactic properties of English or violation of the coherence of allowable lexical concepts. The meaning assigned to *lour* for this experiment was “to look angry or sullen as if in disapproval”. As a verb of facial expression, *lour* takes a subject, an animate agent that can express an emotion facially, and an optional indirect object through the use of the preposition “at” that is the recipient of the verb. The verb does not take a direct object and cannot be passivized. Regular inflectional rules apply for bound grammatical morphemes (e.g. the third person singular is “lours”, the present participle is “louring”, and the past tense form is “loured”).

We constructed our experiment to expose subjects to a representation of *lour* in a naturalistic manner, and then examined the knowledge of *lour* that subjects acquire in three subsequent experiments probing different aspects of the word. Since we naturally acquire words one at a time in the real world, we also decided to teach participants only one word. Indeed, from a methodologic perspective, we could not teach more than a single word to a subject since s/he would have seen the implicit nature of the technique and this would have invalidated the nature of the performance of the word acquired secondly, and would have limited our ability to study the first word one week later. Prior to the exposure period, subjects performed a 10-item lexical decision task that included five familiar verbs, four pseudowords, and “lour.” Subject who endorsed *lour* as a known word were excluded from the data reported below. This eliminated one potential subject (a healthy senior). All subjects included in this study thus reliably distinguished known verbs from pseudowords, and treated *lour* like other pseudowords prior to the exposure period.

Participants were exposed to *lour* in the context of a brief story without any prior indication that they would be learning a new word. Visual illustrations of *lour* were edited from a children’s picture-book (Thompson & Knight, 1999). Images were scanned into a digital format and modified using Adobe Photoshop v6.0 to the specific needs of each stimulus. We assessed each subject’s visual-perceptual processing of complex pictured stimuli with a five item, four-choice, picture-picture matching task. Stimuli for this control task were taken from the same source story as the stimuli for the experiment, and the target stimulus differed from all but one

of the four available choices by one subtle feature. All healthy seniors but one (15 of 16) erred on a single item or less. The remaining healthy senior was not assessed due to an inadvertent omission, but this subject's data were included due to high performance on the remaining tasks and perfect accuracy on the same task at the follow-up one week later (see below). AD patients were equally accurate in their perceptual judgments.

Procedure

In brief overview, subjects were first presented the verb in the context of a narrated picture story, followed immediately by a sentence-picture matching task that reinforced specific aspects of the new verb. After a brief delay, we assessed subjects' mental representation of grammatical, semantic and thematic aspects of the new verb. One week later, we assessed long-term retention of the new verb in healthy seniors and AD patients with alternate versions of the same grammatical, semantic, and thematic tasks.

Exposure Period—The new word was presented without warning in a naturalistic context, embedded in a brief eight-scene picture story, along with the following instructions:

> "I am going to show you a picture-story about a little girl. I will read the story aloud and you can follow along. Pay particular attention to the people in the story and the interactions between them. After we finish the story, I'm going to ask you a few questions about what happened."

Images were paired with a simple narrative printed beneath each picture. The text was read aloud by the experimenter with a natural cadence while the subject followed along. The narrative described an energetic girl who gets into trouble because she fails to obey her father. The final scene of the narrative served as the first exposure to the test verb, pairing *lour* with an illustration depicting an older man in a chair leaning forward and frowning in disapproval at the girl. The participant read and heard the sentence: "Louise sees her father lour at her."

A multiple choice sentence-picture matching task was presented to each subject immediately following the narrative. In each trial, subjects were asked to match one of four pictures to a target sentence. Each sentence was grammatically correct and presented in the active voice using an uninflected form of the verb. Once the subject selected the target picture, positive reinforcement was given and the next example was presented. If a picture other than the target was selected, the subject was told that "most people would select another picture" and instructed to select again. This procedure was continued until the appropriate target picture was identified.

There were nine trials in total. The first two trials served as training for the task and as a memory check to verify that subjects could remember specific events from the story using familiar verbs. Performance on these two questions indicated that all patient groups had good recall of the immediately preceding story. Healthy seniors needed only a single attempt [mean (±S.D.) number of choices=1.00 ±0.00] to identify characters from the story. AD patients required a mean (±S.D.) of 1.70 (±1.83) attempts to identify characters from the story.

The seven remaining, randomly-ordered trials did not depend on specific recall of information from the story, although content from the story was used as stimulus material. Four trials used *lour* and three trials used familiar English verbs. Each trial using *lour* highlighted a specific feature of the verb by manipulating the nature of the incorrect choices. Thus, one trial presented *lour* along with pictures depicting other facial expressions, another trial emphasized that *lour* takes an indirect object rather than a direct object, and a third trial demonstrated that *lour* is associated with a particular preposition. Prior to the post-exposure assessments, a two-minute interference period was filled with a picture-naming task.

Immediate Post-exposure Period—Three post-exposure assessments were presented in a fixed order. We chose this order to limit the amount of information subjects could infer about *lour* from the context of the preceding task(s). Two forms were created for each task, one set was administered during the initial assessment, and the second administered at the one-week follow-up session. Subjects were randomly assigned to one set of materials for the first session. Mann-Whitney U tests comparing performance by healthy seniors detected no differences between forms. This was true for each individual task: Grammar judgments [Z= −0.78; ns]; semantic word-picture matching [Z= −0.45; ns], and thematic matrix judgments [Z= −0.40; ns].

Grammatical sentence acceptability task—Subjects were asked to judge the acceptability of 48 sentences that vary in grammatical appropriateness. This included 14 sentences containing the word *lour*, 22 sentences using a known English verb of facial expression, and 12 sentences with a pronounceable pseudoword. This number of sentences allowed us to balance roughly the number of items for which a "yes" response and a "no" response would be most appropriate. Eight of the sentences with *lour* placed the new verb in a sentence slot normally occupied by a verb, twice without grammatical inflection and six times with a bound grammatical morpheme (equally divided among "-ed", "-ing", "-s"). Performance with these allomorphs was averaged together since preliminary analysis did not indicate a difference between inflectional forms. The remaining six sentences placed *lour* in a non-verb slot in the sentence. These included using the word as a noun (e.g. "The lour saw the man glancing at him"), as an adjective (e.g. "The teachers stare at the lour students"), or as a preposition (e.g. "The woman walked lour the man").

Of the 22 sentences using a familiar verb of facial expression, eight contained the target word used in the active voice without a bound grammatical morpheme, and eight used a known verb in its inflected form (e.g., "-ed", "-ing", or "-s"). The remaining six sentences placed familiar verbs of facial expression into a sentence slot normally occupied by another grammatical word class (equally divided among noun, adjective, or preposition), as described above.

Half of the 12 sentences containing a pseudoword placed these items in a sentence slot normally occupied by a verb ("Shelley foups at both of the dancers"). The remainder were placed in the sentence slot of either a noun, an adjective, or a preposition. The sentences using a pseudoword as a verb included 3 in which the pseudoword appeared uninflected, and 3 in which the inflection of the pseudoword involved the common bound grammatical morphemes used above (i.e. "-ed", "-ing", or "-s").

Sentences were matched for both word count and syllable count, and were presented in a fixed random order. Subjects read each sentence aloud, but they were monitored and corrected for any mistakes. Repetition of sentences was allowed as many times as a subject requested, and there was no time limit for responding. Subjects were instructed to judge each sentence as acceptable or unacceptable (if the sentence "made sense" or was "good or bad"). To ensure patient comprehension, a brief training session was administered prior to the task with known verbs used both correctly and incorrectly, and with pseudowords. Patients thus were exposed to each type of error to minimize confusion about the range of possible errors. The training was repeated if necessary until the examiner felt that the subject understood the instructions and the types of errors.

Semantic picture-word matching task—Acquisition of the meaning of *lour* was assessed with a three-choice, word-picture matching task. To construct stimuli, we first taught young control subjects the meaning of *lour*, and then asked them to name the facial expression of many pictures. Based on their responses, two sets of 30 pictures were selected that were consistently given a single name by test subjects. Each set included 10 pictures in which

"louring" was the preferred name and 20 in which a familiar verb of facial expression was preferred. Each of the pictures was paired with the target verb and two alternate foils. All choices were presented in the progressive form ending with "–ing" (including pseudowords). Alternate foils were a known verb of facial expression, a pseudoword, or "louring." Subjects were asked to select the word that best matched the picture. One healthy senior is not included in this analysis for technical reasons.

Practice examples were given to introduce the task and judge the subjects' task comprehension. This was repeated if necessary. To ensure that impaired accuracy was not the result of a visual-perceptual deficit, patient performance on the semantic picture-word matching task was compared to performance on the 5-item, picture-picture visual-perceptual matching task described above. Kendall tau correlation analysis failed to reveal a significant relationship between performances on these tasks.

Thematic matrix sentence acceptability task—Subjects' acquisition of the appropriate thematic matrix for the new verb was assessed using a second sentence judgment task. Fifty-two sentences were administered, including: 12 containing *lour*, 26 containing a known verb of facial expression, and 14 containing a pseudoword. Six used *lour* as a verb in an appropriate thematic matrix (3 uninflected, 3 with a grammatical inflection). Six violated the thematic coherence of the sentence by placing *lour* with an inanimate agent of the verb (e.g. "The pencils lour at the angry man"), with a sentence complement (e.g. "The boys lour that their mother is angry"), or with a direct object (e.g. "The young men lour the pushy woman").

Sentences using familiar verbs of facial expression included 20 in which the verb was used in its ideal thematic matrix (12 grammatically inflected, 8 uninflected) and six sentences in which the verb was inappropriately paired with a direct object (2 sentences), a sentence complement (2 sentences) or an inanimate agent (2 sentences). Fourteen sentences included a pseudoword used in a sentential slot for a verb (7 sentences) or a noun (7 sentences).

Final instructions at the end of the immediate post-exposure assessment—Subjects were informed that *lour* is a real word, and that a formal definition of the word would be provided after the follow-up session had been completed one week later.

Delayed Follow-up—In order to assess subjects' retention of information about *lour* over a longer delay, we administered the alternate forms of the tasks probing grammatical, semantic, and thematic matrix information about the new verb approximately one week after the initial exposure and immediate post-exposure assessment [controls: mean (±S.D.) 7.56 (± 1.79) days; AD patients: mean (±S.D.) 7.13 (± 0.35) days]. Only 8 of the AD patients were able to participate in the follow-up assessment; the remaining patients were not available for testing because of scheduling conflicts or transportation difficulties. Data in one of these patients was lost due to a technical problem.

Statistical Analyses

We performed two types of analyses: We examined individual patient performance profiles; and we performed more traditional analyses of averaged group performance.

To assess individual patient performance profiles, we first identified an "ideal" pattern of lexical acquisition for each task. Criteria for an ideal performance pattern included: 1) treating the new verb like a known verb of facial expression; and 2) treating the new verb differently from a pseudoword. We verified the occurrence of this profile in individual control subjects, and examined the frequency with which this ideal pattern occurred in AD for each task. Deviation from chance on the binomial or polynomial test was set at $p<0.05$ (for pseudoword judgments on the grammatical task we used $p=0.073$).

We performed more traditional group-wide analyses by averaging across subjects within each group. This allowed us to examine specific error patterns for each class of stimuli within each task. Some statistical analyses used non-parametric tests because of the categorical nature of the data. The significance level for all tests was set at $p<0.05$. All analyses were performed using SPSS statistical software package, v12.0 (SPSS, Chicago, IL, USA).

We found that some healthy seniors and some patients fail to endorse any use of *lour* on a particular task. This phenomenon has been seen in previous work assessing lexical acquisition in healthy adults and patients (Grossman, Stern, Gollomp, Vernon, & Hurtig, 1994; Grossman et al., 1997). Rather than over-interpreting these data as acceptable behavior or impaired behavior, we classified these subjects as "cautious" and excluded them from the analysis. Since some patients exhibited a cautious profile on one task but not on other tasks within the battery, different numbers of testable subjects contributed to performance on each task. "Cautious" patient data were included in the one-week follow-up comparisons due to the instructions at the end of the first session indicating that *lour* is a real word.

RESULTS

Exposure Period

Sixteen (94.1%) of 17 control subjects accurately identified each picture illustrating the test verb on the first attempt. While fewer AD patients identified the picture illustrating the new verb on the first attempt (8 of 11, or 72.7%), this did not differ significantly from controls. Elderly control subjects required an average of 1.08 (±0.21) guesses to accurately match sentences containing *lour* to the appropriate picture. AD patients required more guesses on average to match sentences to the picture illustrating *lour* [1.38 (±1.76)], but this did not differ significantly from controls.

Immediate Post-exposure Assessment

Figure 1 shows that very few individual AD patients demonstrated an ideal pattern of performance for semantic knowledge or for thematic matrix knowledge of *lour*, but a majority of AD patients had an ideal performance profile for grammatical attributes of the new verb. Figure 2 illustrates group-wide averages. This also shows relatively poor performance with semantic attributes of the new verb, intermediate levels of performance judging the new verb's thematic features, and relatively good performance with grammatical attributes of *lour*. We describe performance with each aspect of the new verb in more detail below.

Sentence acceptability judgments for major grammatical subcategory—AD patients were relatively preserved in their grammaticality judgments. Eleven [91.7%] of 12 non-cautious healthy seniors exhibited an ideal profile; the remaining subject was impaired only in his judgments of sentences containing *lour* (Figure 1). As a group, these healthy seniors were accurate in their judgments of sentences containing a real verb [mean = 96.3%; S.D. ±5.4%], judgments of a sentence containing *lour* [mean = 95.7%; S.D. ±5.5%] and judgments of a sentence containing a pseudoword (mean = 94.4%; S.D. ±12.2%].

Five [62.5%] of the 8 non-cautious AD patients exhibited an ideal profile as well, not differing from healthy seniors according to Fisher's exact test. The remaining three [37.5%] AD patients were impaired only in their judgments of sentences containing *lour*.

As a group, non-cautious AD patients were accurate in their judgments of a sentence containing a real verb [mean = 94.1%; S.D. ±5.7%], not differing statistically from controls [$t(25)=1.39$; ns]. Sentences containing *lour* were judged with 76.79% [±14.6%] accuracy, also not differing statistically from controls [$t(25)=1.65$; ns]. These patients also did not differ from controls in

their judgments of pseudowords [t(25)=0.91; ns]. Moreover, a pseudoword was much less likely to be accepted than *lour* in a sentence by controls [t(16)=2.26; p<0.03] and AD patients [t(9)=5.70; p<0.001].

Verb-picture matching for semantic memory—AD patients were significantly impaired relative to controls in their acquisition of semantic properties of the new verb. Thirteen [81.3%] of 16 non-cautious healthy seniors exhibited an ideal performance profile on this task. The non-ideal healthy seniors were impaired only in judgments of *lour*. As a group, word-picture matching accuracy for real words averaged 96.0% [5.5%], and matching accuracy for *lour* was 89.3% [±16.1%].

By comparison, only one [10%] of the 10 non-cautious AD patients showed an ideal profile for semantic attributes of the new verb. This differs significantly from controls [Fisher's exact test p<0.05]. Eight of these AD patients [80%] did not differ from chance in their word-picture matching of *lour*, and three of these AD patients also were impaired judging real words. This difficulty demonstrating an ideal profile for semantic judgments of *lour* also differed significantly from the frequency of an ideal profile for grammatical judgments of *lour* in AD [$\chi^2(1)=5.51$; p<0.05]. Likewise, after converting individual AD patients' grammatical judgments and semantic judgments for *lour* to % correct, we found that 8 of 10 patients were less accurate with semantic judgments than grammatical judgments.

As a group, word-picture matching accuracy for real words in the 10 non-cautious AD patients was somewhat inaccurate [mean = 82.0%; S.D. ±22.1%], differing significantly from controls [t(24)=2.44; p<0.02]. Accuracy for *lour* in these patients was quite impaired [mean = 43.0%; S.D. ±24.9%], also differing significantly from controls [t(24)=5.78; p<0.001]. AD patient were significantly more impaired in their accuracy with *lour* than real words [t(9)=13.83; p<0.001].

Sentence judgments for thematic matrix violations—Twelve [92.3%] of the 13 non-cautious elderly controls exhibited an ideal performance pattern. Thematic matrix judgment accuracy for sentences containing real words was 93.4% [±4.8%] correct in these healthy seniors as a group, while thematic matrix judgment accuracy for sentences with *lour* was 78.9% [±17.6%] correct.

Two [28%] of seven non-cautious AD subjects exhibited an ideal profile, differing from control subjects according to Fisher's exact test [p<0.05]. As a group, thematic matrix judgment accuracy for sentences containing real words in AD patients was 87.8% [±4.9%], differing from control subjects' performance [t(26)=3.28; p<0.005]. Thematic matrix judgment accuracy for sentences containing *lour* was 64.3% [16.9%]. This differed marginally from control subjects' performance [t(26)=2.04; p=0.051]. AD patients' judgments of lour were worse than judgments of real verbs [t(10)=4.34; p<0.001] and worse than their performance with pseudowords [t(10)=4.04; p<0.002].

Delayed Follow-up Assessment

AD patients showed little decline in their acquired knowledge of *lour* over time, as summarized in Table 2. A repeated-measures analysis of variance (ANOVA) thus assessed grammatical judgments of sentences containing *lour* used in correct and incorrect manners over time with a group (2 – control, AD) X time (initial, follow-up) design. There was no group X time interaction [F(1,23)=0.41; ns]. Direct comparisons over time of grammaticality judgments of sentences containing, real words, *lour*, or pseudowords in control subjects and in AD patients were not significant [all p-values >0.10, according to t-tests].

A repeated-measures ANOVA assessed word-picture matching for *lour* over time with a group (2 – control, AD) X time (initial, follow-up) design. We found a significant main effect for group [$F(1,1,22)=11.05$; $p<0.005$] and a group X time interaction that approached significance [$F(1,22)=3.01$; $p = 0.09$]. Within-group comparisons of word-picture matching for real words and *lour* did not reveal any differences in performance for AD patients across the initial assessment compared to the follow-up assessment [all p-values >0.10, according to t-tests]. However, evaluation of word-picture matching performance revealed worse performance at the follow-up assessment compared to the initial assessment in healthy seniors for *lour* [$t(15) =2.50$; $p<0.03$] and for real words [$t(15)=2.41$; $p<0.03$].

A repeated-measures ANOVA assessed thematic matrix judgments over time with a group (2 – control, AD) X time (initial, follow-up) design. This failed to show a significant group X time interaction [$F(1,22)=0.62$; ns]. Direct contrasts of performance at the initial assessment compared to follow-up revealed only a difference for AD patients' judgments of sentences containing *lour* [$t(6)=4.50$; $p<0.001$]. This was due to improved performance in AD patients at follow-up compared to the initial assessment.

DISCUSSION

AD patients showed fragmented acquisition of new word knowledge: As in our previous study, they are impaired at acquiring the new word's meaning, reflecting AD patients' semantic memory difficulties. However, the present study demonstrates that AD patients are able to acquire and represent major grammatical subcategory knowledge associated with a new word. This knowledge appears to be acquired incidentally, and does not seem to require multiple exposures for acquisition to be successful. This observation is most compatible with a modular but interactive architecture of the language system that distinguishes between grammatical and semantic processes. Since this distinction between components of lexical knowledge is represented at a cortical level rather than the hippocampus, these findings appear to provide additional support for the claim that lexical acquisition in amnesics can bypass the hippocampus and occur at the cortical level (Kitchener et al., 1998; Westmacott et al., 2001; Westmacott et al., 2002). Moreover, the present study appears to extend the defect in the new verb's lexical representation to its thematic matrix. This is consistent with the claim that semantic memory contributes to the representation of a verb's thematic matrix. Finally, we find that AD patients are able to retain some of their knowledge about a new verb over the course of a week, even though this was acquired in an incidental manner. Partial success with naturalistic lexical acquisition in AD raises a challenge to previous observations of conceptual implicit memory difficulty in these patients. In the setting of their profound episodic memory deficit, successful acquisition of novel lexical knowledge also appears to suggest that semantic memory in AD is dissociable at least in part from their compromised episodic memory system. We discuss performance on each aspect of verb learning below.

Preserved grammatical processing of novel form class knowledge in AD and the long-term retention of new knowledge

We find that AD patients are able to learn and retain some aspects of a new verb following naturalistic exposure. This success depends on two components: The ability to process the material that is being acquired, and an intact mechanism for learning and retaining this material. Specifically, the new word's major grammatical category is learned and retained more effectively than other components of a single word. Studies of grammatical processing in AD have been controversial. Some work shows successful processing of syntax and grammar in these patients (Blanken, Dittman, Haas, & Wallesch, 1987; Illes, 1990; Irigaray, 1973; Kemper, LaBarge, Ferraro, Cheung, & Storandt, 1993; Kempler, Curtiss, & Jackson, 1987), while other reports describe grammatical impairments (Croot, Hodges, & Patterson, 1999; Emery &

Breslau, 1989; Kempler, Almor, Tyler, Andersen, & MacDonald, 1998; Rochon, Waters, & Caplan, 1994). We and others find that AD patients have difficulty with grammatical processing, but experimental evidence attributes this to a limitation of the executive resources needed to process long-distance grammatical dependencies in a sentence. For example, working memory is needed to retain the head noun phrase in a sentence with a subordinate clause until the trace is encountered in the subordinate clause (Swinney & Fodor, 1989). This kind of long-distance dependency appears to be quite fragile in AD because of their working memory limitations (Grossman & Rhee, 2001; Grossman et al., 1998; Waters & Caplan, 1997; Waters et al., 1998). On the other hand, processing the major grammatical subcategory of a word – knowing that a word is a verb, for example – appears to be managed reasonably well by AD patients. This may be related in part to the minimal executive resources needed to judge a word's grammatical subcategory. Regardless of the basis for this observation, the findings in the present study are consistent with previous observations (Grossman et al., 1997) that AD patients are able to acquire a new word's major grammatical subcategory. This is likely to reflect AD patients' ability to process the grammatical subcategory information of the sentence in which the new word is embedded. Consistent with this view, disease in areas of the brain often associated with grammatical processing such as left inferior frontal cortex typically occurs relatively late in the course of AD (Braak & Braak, 1991).

AD patients are able to acquire this aspect of a verb following naturalistic exposure. By "naturalistic exposure," we mean that the new verb is presented to the patients incidentally and without explicitly indicating that a new word will be heard or that it should be remembered. Naturalistic exposure thus appears to resemble implicit memory in several important ways (Schacter & Tulving, 1994; Squire & Knowlton, 1995). For the most part, this acquisition is relatively effortless and does not require multiple presentations. We reinforce exposure by presenting a forced-choice sentence-picture matching task immediately after exposure, where some of the sentences contain the new word. This too is not very different from how we are exposed to a new word in the real world.

We believe that AD patients are using implicit memory to learn about the grammatical subcategory of the new verb. Previous studies find that implicit memory is relatively preserved in patients with AD, despite their profound episodic memory impairment (Balota et al., 1996; Bondi et al., 1991; Monti et al., 1996). Since naturalistic exposure shares many features with implicit memory, it is possible that this form of lexical acquisition can be achieved in a manner that does not depend on the hippocampal resources needed for episodic memory. While we cannot guarantee that patients are not verbally mediating their knowledge of the new word, we think this is less likely because grammatical knowledge is generally difficult to articulate yet this is the most secure component of verb knowledge that is acquired by AD patients. Indeed, it is not clear why verbally mediated verb acquisition would support only grammatical knowledge.

There is an important distinction between earlier demonstrations of successful implicit memory in AD and the current study. Previous work showing preserved implicit learning in AD focused largely on dot arrays, meaningless visual-perceptual material, and sensory-perceptual attributes of words. Assessments of conceptual implicit memory may not have been as successful at demonstrating learning, by comparison, because the category-exemplar test often used to assess this form of implicit memory also depends in part on substantial executive resources during the category naming component of the test phase (Fleischman et al., 1998; Fleischman et al., 2005). AD patients are impaired in their category naming (LaFleche & Albert, 1995; Mickanin, Grossman, Onishi, Auriacombe, & Clark, 1994). By comparison, the present study examines acquisition of a meaningful word using recognition and judgment tasks that have fewer task-related resource demands. This parallels previous assessments showing acquisition of some novel lexical information in amnesics (Kitchener et al., 1998; Westmacott et al., 2001;

Westmacott et al., 2002). The present findings thus call to question claims that implicit memory is limited to sensory-perceptual material.

To evaluate the power of this implicit approach to lexical acquisition, we reexamined AD patients one week after their initial exposure to the new word. AD patients had been told that *lour* is a real word, although they were told nothing more about the word. Despite episodic memory difficulty, it appears that AD patients largely retain their acquired grammatical knowledge about the new word for a week. The present study thus suggests that elements of a new word can be acquired and retained for an extended period of time. Additional work is needed to help specify the limits of this naturalistic form of exposure to new material, and determine whether it is potentially useful in behavioral therapies for patients suffering from a neurodegenerative disease.

Difficulty acquiring the meaning of a new word in AD

One potential advantage of this naturalistic approach to lexical acquisition is that detailed, multi-faceted aspects of the new word are examined. A word is incredibly complex and involves multiple types of knowledge. Lexical acquisition simultaneously challenges the wide range of language processes needed to acquire a new word. This represents an important way to assess the modularity of a language processing system. While we cannot be absolutely sure that all aspects of a word are equally difficult, we find clearly unequal acquisition of components of the new word. Since these linguistic distinctions are thought to be represented at a cortical level rather than the hippocampus, these observations appear to be most consistent with a cortical basis for novel word learning in AD. The differential acquisition of these lexical components also seems to be compatible with a modular architecture of the language processing system. Of course modularity can occur with different degrees of impenetrability and automaticity, and we do not intend to characterize the language processing system as a modular one in a strong sense (Fodor, 1983). Indeed, as we note below, we view the thematic component of a word in an interactive way that combines semantic and grammatical elements. While there are distributed approaches to lexical representation that minimize components such as grammatical subcategory (McClelland & Patterson, 2002), many studies nevertheless document semantic memory difficulty in AD (Bayles, Tomoeda, & Trosset, 1990; Garrard et al., 1998; Grossman et al., 2003a; Grossman, White-Devine, Robinson, Biassou, & D'Esposito, 1998; Lambon Ralph et al., 2001; Martin, 1992), but relatively preserved grammatical processing apart from working memory difficulty (Grossman et al., 1998; Waters et al., 1998). Consistent with the view that semantic memory is impaired in AD, we find that these patients are relatively impaired at acquiring the new word's meaning.

Lour is a verb. Some work demonstrates that verb meaning is particularly impaired in AD (Robinson et al., 1996; White-Devine et al., 1996; Yi et al., 2006), although others report less impairment for verbs (Fung et al., 2001; Robinson et al., 1999). Several factors may contribute to AD patients' difficulty learning the meaning of a new verb. One possibility may be related to the impoverished hierarchical structure of the semantic network associated with a verb (Jackendoff, 1983; Levin, 1993; Miller et al., 1991). From this perspective, the poorly organized hierarchical structure of a verb limits the systematic incorporation of new entries into the verb semantic network. This contrasts with nouns, where there is a clear hierarchical structure into which a new noun can be integrated. One consequence of this relates to the ability to compensate for disease progression by borrowing shared features from overlapping concepts that are less degraded. A distributed semantic network for nouns thus declines relatively slowly because the well-organized hierarchical structure of these semantic networks facilitates sharing of features with overlapping concepts (Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; Rogers et al., 2004). By comparison, verbs are less well-organized and may be more

vulnerable to the consequences of progressive disease that degrades semantic representations. Additional experimental work is needed to examine this account directly.

Other factors also may contribute to the disproportionate difficulty with the meaning of verbs compared to nouns. One factor concerns the increased resource demands that may be associated with processing all of the knowledge represented in a verb. Although difficulty with verb confrontation naming and verb-picture matching do not correlate with executive resource deficits in AD (Robinson et al., 1996; White-Devine et al., 1996), we cannot rule out that the need to maintain a rich corpus of semantic, thematic, and grammatical knowledge in mind during verb processing may overwhelm AD patients who may have a material-specific limitation of executive resources. Another factor spotlights the potential role that AD patients' impaired thematic matrix knowledge may play in compromised verb meaning. While verb meaning appears to be related in part to the thematic matrix of verb associations in controls, regression analyses show that verb meaning is partially independent of thematic role representations in AD (Grossman, Mickanin, Onishi, & Hughes, 1996).

Since AD patients have profound hippocampal disease, these observations have potential implications for the wider debate about the role of the hippocampus in semantic memory (Tulving, 1972). Some fMRI work suggests that the hippocampus contributes to semantic memory, although the precise role of the hippocampus is debated (Kounios et al., 2003; Moscovitch et al., 2005; Nadel & Moscovitch, 1997; Ryan et al., 2000; Squire & Alvarez, 1995). Other work indicates, however, that patients with semantic dementia have difficulty learning and retaining meaningful information despite relatively intact episodic memory (Graham, Patterson, Pratt, & Hodges, 1999; Snowden, Griffiths, & Neary, 1996). The findings of the present study can be contrasted instructively with observations of lexical acquisition and hippocampal functioning in semantic dementia patients. When semantic dementia patients are taught *lour*, they have significant difficulty learning and remembering aspects of the new word, despite reasonable episodic memory (Murray, Koenig, Antani, McCawley, & Grossman, 2007). Since acquisition of word meaning appears to be at least partially independent of hippocampal functioning in AD and semantic dementia, these observations appear to be consistent with a partial dissociation of semantic and episodic forms of memory. Additional work is needed to determine in greater detail the role of the hippocampus in semantic memory.

Thematic matrix difficulty is related to impaired semantic memory in AD

A verb's thematic matrix governs who is doing what to whom. Verb meaning combines with verb grammatical structure in a thematic matrix (Gleitman, 1990). We find that AD patients have difficulty acquiring a new verb's thematic matrix. Thematic matrix acquisition may be impoverished in AD because the poor acquisition of the semantic component of the new verb limits thematic matrix knowledge. Performance may not be as bad as semantic knowledge, however, because of some successful bootstrapping by the grammatical component of the new verb that is acquired with some success.

Long-term performance with thematic matrix knowledge for the new word improves at the delayed evaluation in AD. It is difficult to attribute this to improved performance with semantic or grammatical features of *lour* over time because sentence grammaticality judgments and word-picture matching are unchanged. Likewise, we doubt that explicit recall of *lour* is responsible for this change because of the patients' poor episodic memory for the new word. Another possibility is concerned with executive resources. Of the three components of *lour* that we examine, performance of healthy seniors suggests that acquisition of thematic matrix knowledge is the most difficult aspect of word learning. Recent observations suggest that executive resources contribute to thematic matrix by integrating grammatical and semantic features. In the acquisition of *lour* by non-aphasic patients with a disorder of social comportment and executive functioning due to frontotemporal dementia, for example, we find

the greatest impairment in their acquisition of thematic matrix knowledge (Murray et al., 2007). We speculate that the demanding nature of thematic matrix knowledge, together with the executive resource limitations of AD patients, prolongs the process of integrating grammatical and semantic knowledge for the purpose of forming a thematic matrix. This is further hampered by the limited semantic knowledge of the new word in AD, ultimately resulting in slowed acquisition of an incomplete representation of thematic matrix knowledge. Additional work is needed to evaluate the role of executive resources in thematic role knowledge.

Conclusion

Several caveats should be kept in mind when interpreting our findings. We do not explicitly pair the target verb with a formal definition, nor do we mention to patients our intention to teach a new word. Despite our use of a very infrequent but real word and our attempts to create a naturalistic setting for learning, the formalized nature of an experimental task may be perceived as artificial and create reluctance to accept the new word as real or to otherwise distort the word's mental representation. In order to assure the reliability of our results, we analyze the data according to two methods: Individual patient profile comparisons and assessments of group scores. Moreover, we obtain several contrasting baselines, including known words and pronounceable pseudowords that have not been previously encountered. These methods reveal reasonably converging patterns of impairment in each group. Our results nevertheless must be interpreted cautiously because of the relatively small number of patients. Generalizing our findings to other verbs classes such as cognition verbs, or to other grammatical subcategories such as nouns, must be performed cautiously. Direct comparisons with other patient groups are necessary to assess hypotheses concerning the role of the hippocampus in the semantic memory impairment of AD patients. We do not have autopsy evidence that the participants indeed have AD, and claims about hippocampal functioning in lexical acquisition thus await direct examination of the brains of these patients.

With these caveats in mind, we find that AD patients can learn about a new verb and maintain this over a week following incidental exposure. They appear to have greater success acquiring the major grammatical subcategory of a new verb than learning its meaning, consistent with previous observations of impaired semantic memory in these patients. The acquisition of thematic matrix knowledge is difficult in AD as well, reflecting the contribution of semantic memory to the thematic matrix properties of a verb. These observations are consistent with a modular but interactive language processing system, and a cortical mechanism underlying lexical acquisition in amnesic AD patients with profound hippocampal disease. The mental representation of grammatical subcategory knowledge of a new word is only one component of partially successful lexical acquisition in AD. A second component is concerned with the process used to acquire this knowledge. Our findings are consistent with the hypothesis that implicit memory is relatively preserved in AD, and that this can be applied to the acquisition of conceptual information like a new word.

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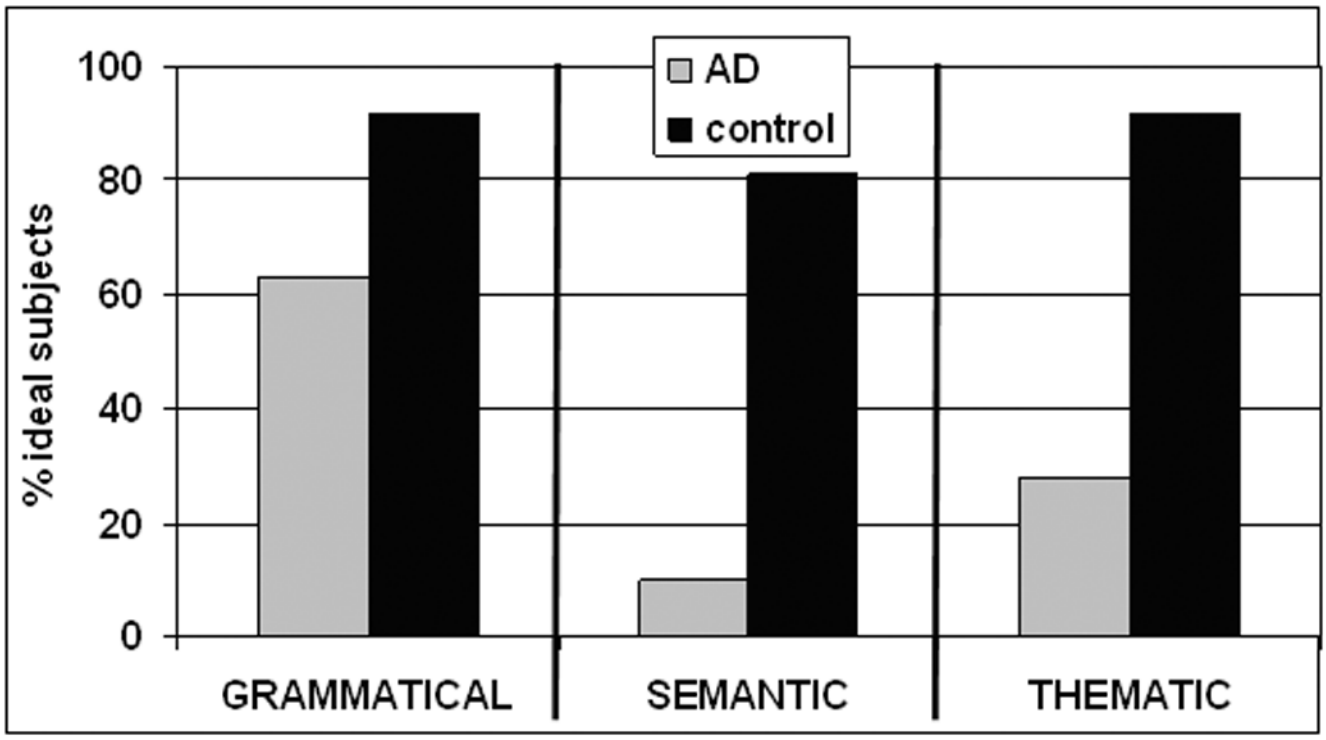

FIGURE 1.
PERCENT OF IDEAL PERFORMANCE PROFILES FOR EACH ASPECT OF THE NEW VERB IN HEALTHY SENIORS AND ALZHEIMER'S DISEASE PATIENTS

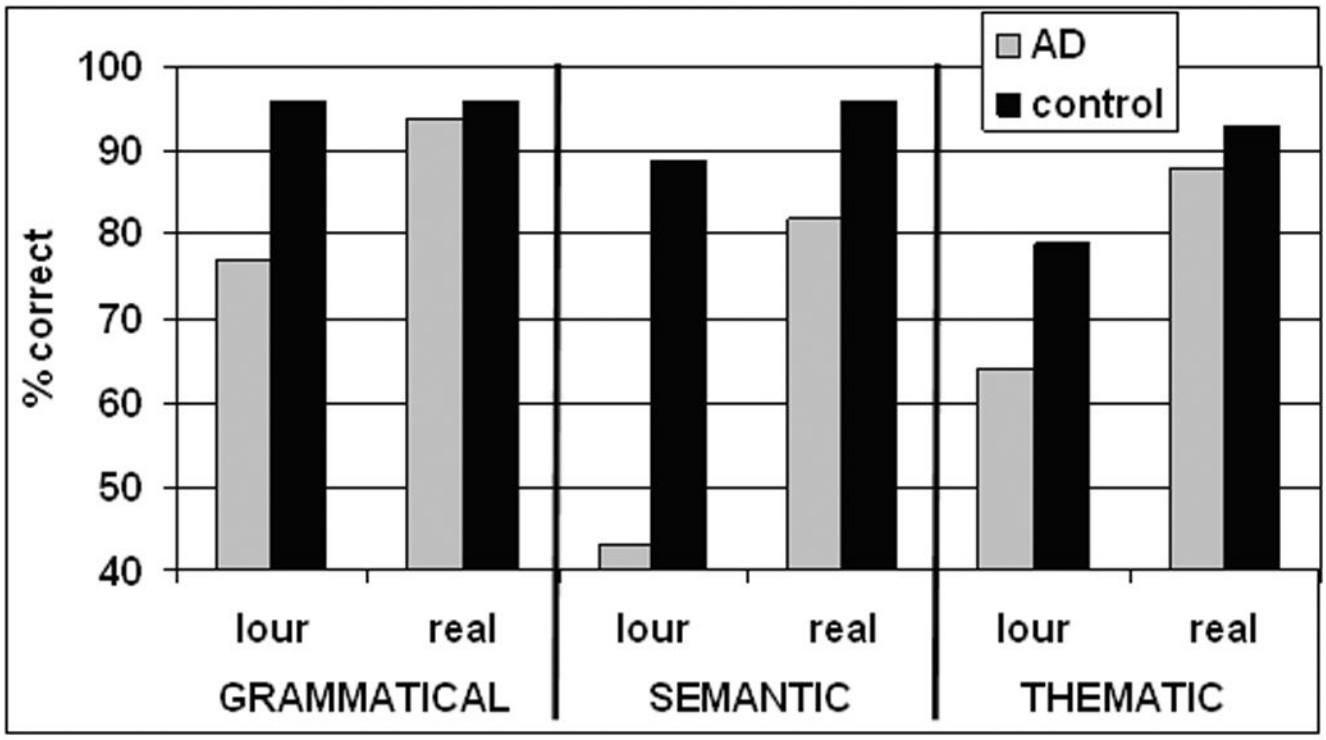

FIGURE 2.
MEAN GROUP PERFORMANCE OF HEALTHY SENIORS AND ALZHEIMER'S DISEASE PATIENTS ON EACH TASK

TABLE 1

CLINCAL AND DEMOGRAPHIC FEATURES OF HEALTHY SENIORS AND ALZHEIMER'S DISEASE PATIENTS[1]

	HEALTHY SENIORS (n=17)		ALZHEIMER'S DISEASE (n=11)	
	Mean	**SD**	**Mean**	**SD**
Age at testing (years)	69.94	9.02	73.83	9.60
Education (years)	15.44	3.18	14.67	2.67
MMSE	29.50	0.63	20.78	8.50
Digit span reverse	4.80	1.30	4.88	1.961
Word list recall total	7.29	1.80	0.75	1.49
Time in trails (sec)	104.80	43.72	213.43	84.07

[1] NOTE Neuropsychological data were available only in 7 of the AD participants.

TABLE 2

INITIAL AND FOLLOW-UP PERFORMANCE IN ALL HEALTHY SENIORS AND ALZHEIMER'S DISEASE PATIENTS PARTICIPATING IN THE LONGITUDINAL PROTOCOL[1]

	Elderly Control (n=17)								AD (n=8)							
	INITIAL				FOLLOW-UP				INITIAL				FOLLOW-UP			
	LOUR		REAL		LOUR		REAL		LOUR		REAL		LOUR		REAL	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	S.D.	Mean	S.D.
Grammatical	93.6	3.1	96.5	3.2	90.2	3.0	98.7	2.4	78.2	24.9	93.8	4.8	62.5	31.5	79.5	28.8
Semantic	89.4	16.0	95.6	5.5	67.5	33.0	92.0	5.0	48.8	25.0	86.9	22.0	51.3	26.0	71.9	19.0
Thematic	78.9	18.7	93.4	5.2	78.9	18.7	94.6	4.8	65.5	15.3	86.1	4.0	72.5	14.5	91.1	4.4

[1] NOTE The data for the initial visit do not correspond to the findings in Figure 1 because the longitudinal analysis included all participants, including the cautious individuals.