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Verb agreements during on-line sentence processing in Alzheimer's disease and frontotemporal dementia ☆

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Abstract

An on-line "word detection" paradigm was used to assess the comprehension of thematic and transitive verb agreements during sentence processing in individuals diagnosed with probable Alzheimer's Disease (AD, $n = 15$) and Frontotemporal Dementia (FTD, $n = 14$). AD, FTD, and control participants ($n = 17$) were asked to listen for a word in a sentence. Unbeknownst to the participants, the target word followed an agreement involving a verb's transitivity or thematic role component. Control participants took significantly longer to respond to a target word only when it immediately followed a violation of a thematic role agreement or a transitivity agreement, relative to target word detection immediately following the corresponding correct agreement. AD patients were selectively insensitive to thematic role agreement violations, although they demonstrated a normal processing pattern for transitivity agreements. This is consistent with previous observations showing selective difficulty with the thematic role component of a verb in AD. FTD patients were insensitive to violations of thematic role and transitivity agreements. FTD patients' impairment for both transitivity and thematic role agreements may reflect a broader degradation of verb knowledge that involves both grammatical and semantic representations, or difficulty processing sentence structure that also causes a thematic role deficit.

Keywords: Sentence comprehension; On-line processing; Verb; Thematic; Transitivity; Alzheimer's disease; Frontotemporal dementia

1. Introduction

Verbs impart information about transitivity and thematic roles. Although there has been much theorizing about these two verb elements (Chomsky, 1965; Grimshaw, 1990; Jackendoff, 1990; Shapiro & Levine, 1990), the neurocognitive basis for comprehending these two components of verb knowledge remains unclear. In the current investigation, we attempted to determine whether these two facets of a verb are dissociable by investigating on-line sentence processing profiles in patients with probable Alzheimer's disease (AD) and Frontotemporal Dementia (FTD).

Verb transitivity and thematic roles represent two core components of verb knowledge. Transitivity is widely thought to be a grammatical feature associated with verb knowledge (Hopper & Thompson, 1980), conveying information about direct and indirect object use (Levin, 1993). For our purposes, transitive verbs are those verbs that require a direct object for a sentence to be correct. Consider the verb 'put.' In the sentence "The boy puts the cup on the table," the verb "put" requires a direct object (i.e., 'the cup'). A transitive verb like "put" without a direct object is incorrect (e.g., "The boy puts on the table"). Intransitive verbs, by comparison, may have an indirect object (e.g., "The boy sleeps on the bed") but should not have a direct object (e.g., "The boy sleeps the bed").

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Verbs also convey meaning about 'who can do what to whom.' This is called "thematic role knowledge." Thematic role knowledge is widely thought to be constrained by the conceptual or semantic structure of a verb (Jackendoff, 1972, 1990). Thematic roles refer to functions that participants and objects play in a sentence, such as 'agent,' 'patient,' 'theme,' 'goal,' 'instrument,' and 'location' (Jackendoff, 1994; Levin, 1993). For example, "The girl puts the cup on the table." In this sentence, 'The girl' is the agent because she is performing the event, 'the cup' is the patient because the event is being performed on it, and 'the table' is the location because it is the place where the cup is being put.

Sentence processing difficulty is a prominent feature of FTD patients with progressive aphasia (Grossman, D'Esposito et al., 1996; Mesulam, 2001; Snowden, Griffiths, & Neary, 1994; Snowden, Neary, Mann, Goulding, & Testa, 1992; Thompson, Ballard, Tait, Weintraub, & Mesulam, 1997; Weintraub, Rubin, & Mesulam, 1990). With rare exceptions, assessments of sentence processing have involved traditional, off-line measures. Task-related resource demands involved with off-line measures (e.g., judging the grammaticality of a sentence or pointing to one of four pictures based on a sentence) confound our ability to assess the relative contribution of syntactic, semantic, and executive components to sentence processing. To circumvent this problem, Tyler, Moss, Patterson, and Hodges (1997) used an on-line word-monitoring technique to assess sensitivity to a grammatical agreement violation in a patient with Progressive Non-fluent Aphasia (PNFA). In this technique, subjects are asked to detect a target word in a sentence. Unbeknownst to subjects, the target word is strategically placed immediately after the grammatical agreement. Healthy subjects ordinarily take several milliseconds longer to respond to the target word when it immediately follows a grammatical agreement violation compared to its detection following a correct grammatical agreement. Evidence to support the claim that this delay is related to the location of the target word in the temporal window for grammatical processing comes from the absence of the delayed response when the target word follows an agreement by several words. The patient studied by Tyler, Moss et al. (1997) was insensitive to the grammatical agreement violation with this on-line technique, as demonstrated by the absence of a delay in target word detection immediately following a grammatical agreement violation. In a subsequent study using the same technique (Grossman, Rhee, & Moore, in press), PNFA patients were insensitive to grammatical agreements such as pluralization, determiner–noun agreement, and Q-float in the immediate temporal window following an agreement violation. However, they were sensitive to a grammatical agreement violation following a delay, suggesting a pattern of slowed activation of grammatical processes. These PNFA patients also were significantly impaired in their off-line sentence comprehension, and their performance correlated with a measure of working memory. Grossman and colleagues hypothesized that knowledge critical to long-distance syntactic dependencies and retained in working memory may have degraded during the slowed grammatical activation.

Several studies have demonstrated that sentence comprehension is compromised in patients with Alzheimer's disease (AD) as well. The basis for this deficit, however, has been unclear. Using traditional measures such as sentence-picture matching and sentence probe tasks, some investigators attributed impaired sentence comprehension to a grammatical deficit (Emery, 1985; Grober & Bang, 1995; Kontiola, Laaksonen, Sulkava, & Erkinjuntti, 1990). More recent work has focused on a limitation in the cognitive resources that contribute to sentence comprehension such as working memory (Almor, Kempler, MacDonald, Andersen, & Tyler, 1999; Croot, Hodges, & Patterson, 1999; Grossman & White-Devine, 1998; Rochon, Waters, & Caplan, 1994; Waters, Caplan, & Rochon, 1995; Waters & Caplan, 1997).

Another potential source of comprehension difficulty in AD may be an impairment at a semantic level of processing that parallels their difficulty with single word comprehension. Although it has been suggested that AD patients experience some grammatical difficulty as shown by their deficit matching a brief sentence containing a quantifier violation such as "The glass contains much milk" or "The bowl has many cereal" to one of four pictures (Grossman, Mickanin, Onishi, & Hughes, 1995), many other studies demonstrate semantic difficulties. For example, AD patients have shown an impaired ability to correctly identify incorrect semantic agreements such as "The door is singing," in which the agent 'door' violates the selection restriction associated with the predicate 'is singing' (Grossman, Mickanin, Robinson, & D'Esposito, 1996). In another study examining the ability to learn the grammatical and thematic aspects of the new verb "wamble," AD patients were found to acquire information about its grammatical properties (e.g., the new word is a verb that plays a particular grammatical role in a sentence), but had difficulty learning about the new word's thematic role properties (Grossman, Mickanin, Onishi, Robinson, & D'Esposito, 1997). Another recent study used an on-line word detection task to demonstrate that AD patients have impaired sensitivity to semantic agreement violations such as "The handsome young man pointed the *yellow* in the right direction" (Grossman & Rhee, 2001; Rhee, Antiquena, & Grossman, 2001). AD patients nevertheless showed relatively normal sensitivity to grammatical agreement violations involving pluralization and negation agreements. This sensitivity occurred, however, in a manner that was delayed beyond the normally rapid temporal processing window for the target grammatical agreement. These findings emphasized the contribution of a semantic limitation to impaired sentence processing in AD, and related a grammatical processing deficit to resource limitations like slowed information processing speed.

While previous work has examined sentence comprehension in FTD and AD from the perspective of processing deficits associated with long-distance syntactic dependencies, another possibility is that these patients have impaired sentence comprehension because of a deficit related to impaired verb knowledge. Verbs are at the core of a sentence, guiding sentence features such as thematic role assignment and transitivity. It appears that FTD patients and AD patients have difficulty with verbs. Patients with FTD are reported to have impaired naming of verbs relative to nouns (Cappa, Binetti, et al., 1998; Rhee, Antiquena, et al., 2001). A study by Rhee, Antiquena, et al. (2001) compared noun and verb comprehension alone and during a concurrent dual task in patients diagnosed with FTD. These patients were significantly less accurate and required significantly longer to make word-picture matching judgments about verbs relative to nouns at baseline. During concurrent performance on a secondary task, accuracy decreased and response latencies became prolonged for nouns to the point that these measures equaled performance with verbs at baseline. Several studies have shown that AD patients have a small but consistent disadvantage in their comprehension and naming of verbs compared to nouns (Cappa, Binetti, et al., 1998; Robinson, Grossman, White-Devine, & D'Esposito, 1996; White-Devine et al., 1996), although exceptions to verb difficulty have been seen in individual patient analyses in these studies and in other reported cases (Fung, Chertkow, et al., 2001; Robinson, Rossor, & Cipolotti, 1999). In one study that taught AD patients a new verb, difficulty was seen in acquiring thematic information, although the patients were able to acquire knowledge such as major grammatical form class (Grossman, Mickanin, et al., 1997). Work noting AD patients' impairment for function features (Johnson & Hermann, 1995; Lambon Ralph, Graham, Ellis, & Hodges, 1998) implies an impairment in verb thematic relations representing "who does what to whom."

In the present study, transitivity and thematic role components of verb knowledge were investigated in individuals diagnosed with AD and FTD while using an "on-line" sentence processing procedure. We used the on-line word-detection technique pioneered by Marslen-Wilson and Tyler (1980) to assess processing of these verb elements while minimizing confounds associated with the executive resource limitations observed in AD (Almor, Kempler, et al., 1999; Croot, Hodges, et al., 1999; Grossman & White-Devine, 1998; Kempler, Almor, Tyler, Andersen, & MacDonald, 1998; Rochon, Waters, et al., 1994; Waters et al., 1995; Waters & Caplan, 1997) and FTD (Elfgren, Passant, & Risberg, 1993; Hodges, Patterson, et al., 1999; Miller, Cummings, et al., 1991; Pachana, Boone, Miller, Cummings, & Berman, 1996). In the present study investigating verb-related sentence agreements, we hypothesized different patterns of sensitivity to thematic and transitivity agreements. We expected AD patients to show limited sensitivity to thematic role agreements because of the rich semantic component of this agreement, but normal sensitivity to transitivity agreements. However, FTD patients were expected to demonstrate limited sensitivity to thematic (i.e., semantically related) and transitivity (i.e., grammatical) agreements associated with verbs because of their broader deficit with verbs.

2. Methods

2.1. Participants

A total of 46 right handed native English-speakers were included in this investigation. Fifteen individuals with AD and 14 individuals with FTD were recruited from the Cognitive Neurology Clinic at the Hospital of the University of Pennsylvania. These patients were compared with 17 non-depressed, right-handed, high school-educated, native English-speakers who were neurologically intact.[1] The demographic features of the participants are summarized in Table 1. The three groups were matched for education [$F(2,43) = 0.24$; ns] and age [$F(2,43) = 3.21$; ns]. The AD and FTD groups were equivalent in their overall dementia severity, as measured by the Mini Mental State Exam (Folstein, Folstein, & McHugh, 1975) ([$t(27) = 0.45$; ns]). There was no difference in male/female ratios across groups [$\chi^2(2) = .70$; ns]. The control subjects were recruited from among the spouses of the patients. The diagnosis of AD was made according to the National Institute of Neurologic and Communicative Disorders and Stroke-Alzheimer's Disease and Related Disorders Association criteria (McKhann, Drachman, et al., 1984). Diagnosis for FTD was made according to published criteria (Lund/Manchester, 1994; McKhann, Albert, et al., 2001). Patients with FTD were placed into three subgroups (Progressive Non-Fluent Aphasia, PNFA; Semantic Dementia, SD; Executive dysfunction, EXEC) based on published criteria (Neary, Snowden, et al., 1998), as modified by Davis, Price, Moore, Campea, and Grossman (2001) and Price, Davis, Moore, Campea, and

[1] Fifty-nine participants were originally tested (19 controls, 17 AD, and 23 FTD patients). This participant dataset that we are reporting was reduced in size for the following reasons: *CONTROLS:* 1 scored in the severely depressed range on the Geriatric Depression Scale (Sheikh & Yesavage, 1986), 1 scored below the normal cut-off of 24 on the MMSE; *AD:* 1 reported ambidexterity, 1 was unable to comprehend instructions for the on-line sentence task; *FTD:* 3 developed clinical features of Corticobasal Degeneration with longitudinal follow-up, 4 were unable to effectively comprehend sentence task, 1 did not have English as a first language, and 1 did not complete the protocol due to a time constraint.

Table 1
Mean (±*SD*) demographic features in the Control Group (Con), Alzheimer Disease (AD), Frontotemporal Dementia (FTD overall), and FTD subgroups (Progressive Nonfluent Aphasia, PNFA, Semantic Dementia, SD; Executive dysfunction, EXEC)

	Age (years)	Education (years)	MMSE (max = 30)
Con ($n = 17$)	73.24 (±10.45)	14.06 (±3.00)	28.94 (±1.25)
AD ($n = 15$)	75.67 (±5.72)	14.73 (±2.52)	21.67 (±4.81)
FTD ($n = 14$)	67.79 (±8.51)	14.29 (±2.84)	22.57 (±5.96)
PNFA ($n = 6$)	74.17 (±4.83)	13.50 (±1.97)	21.00 (±7.48)
SD ($n = 6$)	64.33 (±7.15)	15.33 (±3.72)	23.00 (±5.29)
EXEC ($n = 2$)[a]	59.00 (±9.90)	13.50 (±2.12)	26.00 (±1.41)

[a] For the FTD subgroup analyses, the EXEC group was not examined due to the small number of patients representing this group diagnosis.

Grossman (2001) to improve reliability. A consensus mechanism was used to assign patients to diagnostic groups. At least two trained reviewers considered a semi-structured history, a detailed mental status exam, and a full neurologic exam to classify patients. When there was a disagreement (11% of patients), the full committee resolved the difference through discussion. Exclusion criteria included the presence of other causes of dementia such as vascular disease [Hachinski ischemia scores (Rosen, Terry, Fuld, Katzman, & Peck, 1980) were 2 or less in all patients], primary psychiatric disorders such as depression or psychosis, medical illnesses or metabolic derangements that may result in an encephalopathy, infection diseases that may result in a progressive intellectual decline, and other neurological conditions affecting the central nervous system that may impact cognitive performance. None of the patients were taking sedating medications at the time of testing. Additionally, because our investigation assessed auditory sentence comprehension, all patients were assessed with an auditory discrimination test for words, Wepman's Auditory Discrimination Test (Wepman & Reynolds, 1987).

2.2. Materials and procedure

2.2.1. Word detection procedure

The sentence stimuli for the sentence comprehension tasks were designed around 30 verbs (15 transitive and 15 intransitive). These verbs were selected from a group of 187 intransitive and transitive verbs that were initially identified from *The American Heritage Dictionary of the English Language* (1996) based on their 'pure' transitive and intransitive properties, and then judged for familiarity by 64 individuals (42 undergraduates, 22 healthy seniors). Only those verbs endorsed as familiar by 100% of these individuals were candidates for inclusion in this study. The transitive and intransitive verbs were matched for English corpus frequency using Francis and Kucera (1982) norms [$t(28) = 0.67$; ns], syllable length [$t(28) = 0.75$; ns], and letter length [$t(28) = 0.13$; ns].

Each verb was represented in six types of sentences that used a simple present tense Noun Phrase–Verb Phrase format limited to an average of eight words per sentence [mean # of words per sentence = 8.06; $SD = 0.62$]. The transitive and thematic violations, and the corresponding control sentences (i.e., containing coherent agreements), were created from judgment responses of 55 undergraduate students who were recruited to rate each sentence for plausibility. For this judgment task, each undergraduate was asked to read each sentence and identify whether the sentence was 'plausible,' 'somewhat plausible,' or 'not plausible.' This task was conducted to ensure that only the control sentences contained coherent semantic and grammatical agreements relative to the sentences that contained agreement violations. For example, it was imperative that the thematic control sentences had a coherent subject–verb relationship (such as 'The cat scratches…'), in contrast to sentences containing a thematic violation (such as 'The air scratches…'). Appendix A lists the sentence stimuli.

Based on a paradigm introduced by Marslen-Wilson and Tyler (1980) and Tyler (1985), each trial began with the aural presentation of a target word. Then a brief auditory warning signal was heard 500 ms prior to the aural presentation of a sentence. Participants were instructed to press the space bar on the computer as soon as the target word was heard in the sentence. This button press stopped the computer's clock that had been initiated at the beginning of the target word in the sentence. Without informing the participants, half of the sentences contained an agreement violation prior to the target word. Within these sentence violations, 33% contained a transitive/intransitive violation, and 33% contained a thematic agreement violation, and 33% of the remaining sentences served as fillers containing other kinds of violations. Each violation condition also had an equal number of control sentences that consisted of identical sentences—the only difference was that they did not contain a violation.

Two time window conditions for each violation and control sentence were used to establish the temporal envelope for agreement processing. These two time window conditions included an immediate condition (the agreement under investigation was immediately followed by the target word) and a four-syllable delay condition (the target word followed the agreement of interest with four intervening syllables). Pilot investigations showed that unstressed grammatical morphemes such as 'a' or 'the' are more difficult to identify than content words such as adjectives, adverbs, or nouns during this on-line auditory word detection task. For this reason, both the immediate and delay target words for all sentences were content words (i.e., nouns, adverbs, and adjectives) rather than articles (i.e., 'a,' 'the'). Each target word was also tested for predictability within its sentence context using a cloze procedure. Immediate and delay target word predictability was assessed by a group of undergraduate students (total $n = 44$) with a cut-off rule requiring that the target could not be judged as predictable by more than 10% of the undergraduates. In addition to these criteria, all target words in each sentence type were matched for frequency of use in the English corpus (Francis & Kucera, 1982) and the types of sentence violations contained an equal number of noun, prepositions, adverb, and adjective targets [$\chi^2(6) = 4.38$; ns].

Overall, across all of these conditions, a total of 360 sentences were presented to each participant. The 360 sentences were divided into four balanced blocks of stimuli. Each block contained 90 sentences with equal numbers of randomly ordered violations and control items. Each sentence block took approximately 15–20 min to complete. A stimulus sentence containing an agreement violation and its paired control sentence featuring the corresponding coherent agreement were placed in different blocks, and these were distributed so that pairs of blocks containing these pairs of sentences were administered in different sessions separated by 2–4 weeks. To ensure that participants were listening to sentences and not merely performing a vigilance test for a single word, each participant's knowledge of the content of 10% of the correct sentences in each block was probed randomly after a target word response was elicited: They were asked a question about a fact in the sentence and required to provide an answer. Patients who were unable to complete this requirement were excluded from the study.

A training procedure was designed with six sentences to introduce the participants to the word detection paradigm, to familiarize them with the response modality, and to prepare them for random question probes during the course of stimulus sentence presentation. Each participant was given up to five repetitions of this training procedure before the experimental testing procedure began. Patients who could not complete the training procedure were excluded from the study.

The stimuli were digitized by SoundEdit v2.0 software using 16 bit sound files, stimulus presentation was controlled by PsyScope v1.2.5 software (Cohen, MacWhinney, Flatt, & Provost, 1993), and a Macintosh G3 laptop computer was used to administer the stimuli and record the responses. Latencies to respond to the target words were analyzed once very long (>10 s) and very short (<100 ms) responses had been eliminated, and the remaining responses had been screened within each participant using a two-standard deviation filter based on each participant's mean response latency. This resulted in the elimination of equal percentages of items from the protocol for control participants [mean ± $SD = 7.14 \pm 4.20\%$], AD patients [mean ± $SD = 5.91 \pm 4.26\%$], and FTD patients [mean ± $SD = 8.57 \pm 4.58\%$; $F(2,43) = 1.37$, ns].

2.2.2. Additional cognitive background tasks

Measures of language and executive function were administered to all participants. These included:

Test for the Reception of Grammar (TROG; Bishop, 1989)—The TROG is an 80-item four-choice sentence-picture-matching test. It is divided into 20 blocks of four items each, with each block testing a different lexical, morphosyntactic or syntactic construction. A block is scored as passed only if all four items within it are answered correctly. Later blocks are generally more difficult than earlier blocks. The dependent variable included total number of items correct.

Pyramid and Palm Tree Test (PPT; Howard & Patterson, 1992)—This test is designed to measure semantic associates for concrete noun words and pictured objects. For the purpose of this experiment, individuals were tested on their ability to judge the associativity of 52 word sets in a forced-choice, two-alternative format (e.g., given the target 'Glass,' which of these two words goes best with the target: 'Bottle,' 'Mug,'). The dependent variable included total number of items correct.

Verb Similarity Task (VST)—The VST uses a forced-choice, 2-alternative format (paralleling the *Pyramid and Palm Tree Test*) to assess low and high synonym associativity. This task presents a target verb visually centered on a computer screen and above two other verbs. The participant is required to choose which of these two words is most similar in meaning to the target word. For this task, we attempted to control for differences in verb semantic representation (verb of motion, verb of cognition, and verb of perception) and argument structure (transitive vs. intransitive). To identify the semantic representation of each target word, we recruited 58 individuals (English first language; 35 undergraduate students; 23 healthy seniors) to categorize 187 verbs as either a verb of motion or a verb of perception/cognition. From this set, 50 verbs were identified (25 verbs of motion, 25 perception/cognition verbs). Together, these 50 verbs included 25 transitive verbs, 19 intransitive, and 6 verbs that could be either transitive or intransitive depending on sentence role (as identified from *The American Heritage Dictionary of the English Language* (1996)). The forced-choice responses for the task were developed based on a normative database in which undergraduate students ($n = 86$; all native English-speakers) were asked to listen to each target verb and immediately list at least five associated verbs. The participants were provided with practice examples prior to administration of the task (i.e., "The verb SNEEZE might generate the verbs BLOW, SNIFF…"). The correct answer and competing foils were selected according to the frequency of response. The original 50 triads were reduced to 48 when we found that healthy seniors were performing at chance on two of the items. Items were presented in a random order, and the correct force-choice responses were balanced in their right vs. left location. For the verb task, all targets and forced-choice responses were matched for English corpus frequency and for their use as a verb with at least a 5:1 verb/noun ratio using Francis and Kucera (1982) norms [frequency $F(2,141) = 1.80$, ns; verb/noun ratio $F(2,141) = 0.71$, ns]. In addition, all targets and responses were matched in English corpus frequency to that of the *Pyramid and Palm Tree Test* triads [frequency $t(298) = 0.18$, ns].

Trail Making Test Part B (Trails B test; Reitan, 1958)—A measure of planning and inhibitory control that requires participants to trace a line between an ascending series of alternating numbers and letters randomly arrayed on a printed page. Our dependent variable included the amount of time required to complete the task (one AD patient refused to complete the Trail B test).

2.2.3. Statistical considerations

Raw reaction times were recorded for the number of milliseconds it took a person to respond to a target word following a verb agreement that is correct or incorrect. From these raw reaction times, difference scores were computed. The equation for the "difference score" was: [ms reaction time to a target word following an incorrect agreement – ms reaction time to a target word following a correct agreement]. Sensitivity to an agreement violation involves a delay in reaction time to target word detection immediately after the abnormal agreement relative to target word detection immediately following a correct agreement. However, a return to baseline following completion of processing for the grammatical agreement is demonstrated by equivalent latencies to target word detection following an incorrect agreement and a correct agreement by about four syllables downstream from the violation. To assess this normal processing pattern, an immediate "difference score" and a delay "difference score" were computed. The equation for the immediate "difference score" was: [ms reaction time to a target word immediately following an incorrect agreement – ms reaction time to a target word immediately following a correct agreement]. The equation for the delay "difference score" was: [ms reaction time to a target word located four syllables downstream from the incorrect agreement – ms reaction time to a target word located four syllables downstream from the correct agreement]. If normal processing is demonstrated, then the "difference score" for the immediate position should be greater than the "difference score" occurring downstream from the verb's agreement. We conducted a repeated measures ANOVA to examine performance differences between participant groups. Within-group analyses were conducted for each participant group as well, to confirm that normal processing with the sentences took place for the health senior control group and to examine our specific hypotheses about AD and FTD performance patterns for the transitive and thematic conditions. For the within-group analyses, two sets of pair-wise comparisons were conducted for each participant group. First, for each sentence condition, we conducted pair-wise comparisons of immediate and delayed "difference scores." Second, to confirm sensitivity patterns, follow-up planned comparisons were conducted between raw reaction times to target words following incorrect agreements and raw reaction times to correct agreements. Tables 2 and 3 provide the raw reaction times for both the thematic and transitive conditions.

3. Results

3.1. Repeated measures ANOVA

A 3 (Group: Control, AD, FTD) × 2 Sentence Condition (Thematic, Transitive) × Time (Immediate, Delay) Repeated Measures ANOVA was used to examine

Table 2
Mean (±*SD*) millisecond reaction time for the thematic conditions (control/violation) by target position (immediate/delay) for the Control (Con, $n = 17$), Alzheimer Disease (AD, $n = 15$), Frontotemporal Dementia (FTD overall, $n = 14$), and FTD subgroups (Progressive Nonfluent Aphasia, PNFA, $n = 6$; Semantic Dementia, SD, $n = 6$; Executive/social dysfunction, EXEC, $n = 2$)

	Thematic control		Thematic violation	
	Immediate	Delay	Immediate	Delay
Con	493.14 (±84.24)	451.07 (±69.93)	536.55 (±89.65)	453.76 (±63.60)
AD	653.57 (±220.45)	585.53 (±251.27)	682.12 (±178.67)	600.33 (±251.44)
FTD	814.09 (±210.91)	737.78 (±298.31)	844.77 (±194.54)	695.08 (±200.99)
PNFA	854.82 (±191.49)	811.97 (±353.78)	862.06 (±209.20)	753.19 (±260.55)
SD	777.60 (±257.80)	677.86 (±286.07)	843.47 (±221.06)	640.78 (±171.41)
EXEC	810.38 (±210.65)	694.93 (±252.31)	796.77 (±149.68)	600.33 (±251.44)

Table 3
Mean (±*SD*) millisecond reaction time for the thematic conditions (control/violation) by target position (immediate/delay) for the Control (Con, $n = 17$), Alzheimer Disease (AD, $n = 15$), Frontotemporal Dementia (FTD overall, $n = 14$), and FTD subgroups (Progressive Nonfluent Aphasia, PNFA, $n = 6$; Semantic Dementia, SD, $n = 6$; Executive/social dysfunction, EXEC, $n = 2$)

	Transitive control		Transitive violation	
	Immediate	Delay	Immediate	Delay
Con	516.08 (±85.92)	473.55 (±72.90)	548.32 (±74.33)	465.83 (±74.81)
AD	642.08 (±146.71)	609.02 (±177.24)	676.73 (±136.35)	594.16 (±155.00)
FTD	828.31 (±212.94)	737.78 (±298.31)	844.77 (±194.54)	695.08 (±200.99)
PNFA	814.69 (±132.05)	866.44 (±386.58)	810.55 (±181.84)	762.91 (±281.40)
SD	798.77 (±220.62)	680.68 (±179.00)	874.51 (±330.34)	644.29 (±167.65)
EXEC	957.82 (±467.99)	717.42 (±354.00)	767.25 (±255.76)	698.81 (±197.91)

differences in group sensitivity patterns to each of the sentence conditions. The between-group main effect was not significant [$F(2,43) = 2.53$, $p = .09$] but suggested a trend for the FTD patients to be less sensitive than the other groups regardless of sentence type or violation position (millisecond overall difference score mean ± SD by group: FTD = −17.80 ± 12.83; AD = 15.79 ± 12.30; Control = 17.65 ± 11.64). In regard to main effects, a significant effect of Time [$F(1,43) = 8.64$, $p < .005$] confirms that all participants, regardless of group diagnosis, demonstrated greater reaction times to the targets immediately following any sentence violation (mean ± *SD* = 28.83 ± 10.59) relative to the four-syllable delay position (mean ± *SD* = −18.40 ± 10.85). There were no significant two-way or three-way interactions [Group × Time: $F(2,43) = .27$, ns; Group × Sentence type: $F(2,43) = .24$; Group × Sentence Condition × Time: $F(2,43) = .28$, ns]. We interpret these findings as supportive of the validity of our sentence processing paradigm in general.

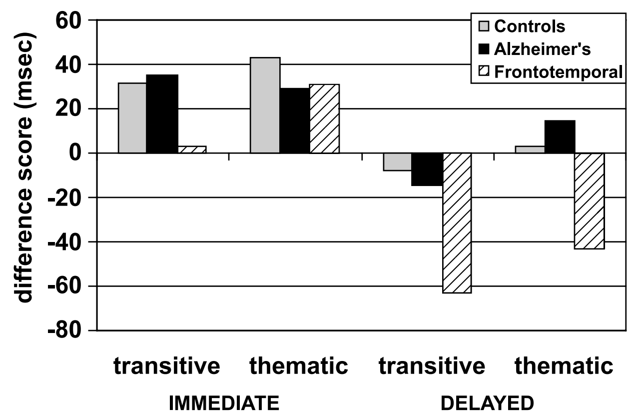

Fig. 1. Group difference scores for the thematic and transitive agreement conditions by target word position (Immediate/delayed). The equation for the "difference score" was: [ms reaction time to a target word following an incorrect agreement − ms reaction time to a target word following a correct agreement].

3.2. Within group comparisons for transitive and thematic conditions

3.2.1. Healthy seniors

Healthy seniors demonstrated normal sensitivity to both transitivity and thematic agreements. Specifically, for the transitivity agreement condition, the healthy seniors had a greater "difference score" in the immediate temporal window [mean ± *SD* = 32.24 ± 54.91 ms] relative to the "difference score" during the delayed temporal window [mean ± *SD* = −7.71 ± 30.02 ms; $t(16) = 3.23$, $p < .006$]. These difference scores are illustrated in Fig. 1. In the immediate "difference score" position, follow-up planned analyses showed that healthy seniors demonstrate a prolonged reaction time latency to a target word following the incorrect transitivity agreement [mean ± *SD* = 548.32 ± 74.33] relative to a correct transitivity agreement [mean ± *SD* = 516.08 ± 85.92 ms; $t(16) = 2.42$, $p < .03$]. This reaction time latency pattern was not observed in the delayed "difference score" position [delayed incorrect agreement mean ± *SD* = 465.83 ± 74.80 ms; delayed correct agreement mean ± *SD* = 473.55 ± 72.90 ms; $t(16) = 1.06$, ns]. These findings suggest that the healthy seniors exhibited normal sensitivity for the transitivity component of a verb's representation.

Healthy seniors also had a normal processing pattern for the thematic agreements. As shown in Fig. 1, these participants had a greater "difference score" for the thematic agreements in the immediate temporal window [mean ± *SD* = 43.41 ± 36.97 ms] relative to the "difference score" for the thematic agreements in the delayed temporal window [mean ± *SD* = 2.68 ± 31.14 ms; $t(16) = 3.87$, $p < .002$]. Specifically, the greater immediate "difference score" involved longer latencies to the target words following an incorrect thematic agreement [mean ± *SD* = 536.55 ± 89.65 ms] relative to a correct thematic agreement [mean ± *SD* = 493.14 ± 84.24; $t(16) = 4.84$, $p < .001$]. A difference in latency following incorrect and correct thematic agreements was not observed for target words in the four-syllable delay position [delay incorrect agreement mean ± *SD* = 453.76 ± 63.59 ms; delay correct mean ± *SD* = 451.07 ± 69.93; $t(16) = 0.36$; ns]. These findings suggest that the healthy seniors exhibited normal processing for the component of verb representation involving thematic agreements.

3.2.2. AD patients

AD patients were sensitive to transitivity agreements but not thematic agreements, as shown in Fig. 1. Thus, resembling healthy seniors, the AD patients demonstrated a greater "difference score" for the transitivity agreement in the immediate temporal window [mean ± $SD = 34.65 \pm 50.86$ ms] compared to the "difference score" in the delayed temporal window [mean ± $SD = -14.86 \pm 67.02$ ms; $t(14) = 3.93$, $p < .002$]. Planned comparisons confirmed that the AD patients' "difference score" for transitivity agreements in the immediate temporal window involve longer latencies to the target words following incorrect agreements [mean ± $SD = 676.73 \pm 136.35$ ms] compared to correct agreements [mean ± $SD = 642.08 \pm 146.71$ ms; $t(14) = 2.64$, $p < .02$]. This difference between latencies for incorrect and correct agreements was not observed for target words in the four-syllable delay position [delay incorrect agreement mean ± $SD = 594.16 \pm 154.99$ ms; delay correct mean ± $SD = 609.02 \pm 177.24$ ms; $t(14) = 0.86$, ns]. These findings indicate that the AD participants normally processed the verb grammatical agreement involving transitivity.

For the thematic agreement, however, the AD patients did not demonstrate a greater "difference score" in the immediate temporal window relative to the "difference score" in the delayed temporal window [immediate mean ± $SD = 28.56 \pm 64.14$ ms; delay mean ± $SD = 14.80 \pm 41.80$ ms; $t(14) = 0.79$; ns]. Moreover, AD patients did not demonstrate a longer latency to respond to a target word following the incorrect thematic agreements, relative to the correct thematic agreements, in either the immediate temporal window [incorrect agreement mean ± $SD = 682.12 \pm 178.67$ ms; correct agreement mean ± $SD = 653.57 \pm 220.45$ ms; $t(14) = 1.72$; ns] or the delayed temporal window [incorrect agreement mean ± $SD = 600.33 \pm 251.44$ ms; correct agreement mean ± $SD = 585.53 \pm 251.27$ ms; $t(14) = 1.37$; ns]. This finding indicates that the participants diagnosed with AD were insensitive to thematic agreement violations.

3.2.3. FTD patients

As a group, Fig. 1 shows that FTD patients were insensitive to both transitivity and thematic agreements. For the transitivity agreement, the FTD patients did not demonstrate a greater "difference score" in the immediate temporal window relative to the "difference score" in the delayed temporal window [immediate mean ± $SD = 3.46 \pm 167.65$ ms; delay mean ± $SD = -62.63 \pm 129.96$ ms; $t(13) = 1.04$; ns]. Moreover, the FTD patients did not demonstrate a longer latency to detect a target word following incorrect agreements, relative to correct agreements, in either the immediate temporal window [incorrect agreement mean ± $SD = 831.78 \pm 247.81$ ms; correct agreement mean ± $SD = 828.31 \pm 212.94$ ms; $t(13) = 0.08$; ns] or the delayed temporal window [incorrect agreement mean ± $SD = 702.92 \pm 218.01$ ms; correct agreement mean ± $SD = 765.54 \pm 296.34$ ms; $t(13) = 1.80$; ns]. This finding indicates that, unlike healthy seniors and AD patients, the FTD patients were insensitive to transitivity agreements.

For the thematic condition, FTD patients did not demonstrate a greater "difference score" in the immediate temporal window relative to the "difference score" in the delayed temporal window [immediate mean ± $SD = 30.67 \pm 124.30$ ms; delay mean ± $SD = -42.69 \pm 148.01$ ms; $t(13) = 1.15$; ns]. Moreover, FTD patients did not demonstrate a longer latency to detect a target word following the incorrect thematic agreements, relative to the correct thematic agreements, in either the immediate temporal window [incorrect agreement mean ± $SD = 844.77 \pm 194.54$ ms; correct agreement mean ± $SD = 814.09 \pm 210.91$ ms; $t(13) = 0.92$; ns] or the delayed temporal window [incorrect agreement mean ± $SD = 695.08 \pm 200.99$ ms; correct agreement mean ± $SD = 737.78 \pm 298.31$ ms; $t(13) = 1.08$; ns]. This finding indicates that the participants diagnosed with FTD, like patients with AD, were insensitive to thematic agreements.

As with the Control, AD, and FTD groups, within-group analyzes were conducted for the PNFA ($n = 6$) and SD ($n = 6$) subgroups of FTD patients to examine their performance on the transitive and thematic violations. Due to the small number of participants in the PNFA and SD subgroups of FTD, the within-group performance on the transitive and thematic violations were analyzed with the nonparametric Wilcoxon Signed Ranks Test. We did not analyze the EXEC subgroup separately because of the small number of these patients.

For the transitive condition, the PNFA subgroup of FTD patients did not demonstrate a discrepancy between the "difference score" immediately following a transitive agreement [mean ± $SD = -4.14 \pm 131.55$ ms] compared to a four-syllable delay [mean ± $SD = -103.53 \pm 186.26$ ms; $Z = .31$; ns]. None of the latencies to target words following correct vs. incorrect agreements differed in either temporal window [all p values at least >0.10, according to t tests]. For the thematic condition, the PNFA subgroup did not demonstrate a significant discrepancy between the "difference score" immediately following a thematic agreement [mean ± $SD = 7.24 \pm 125.50$ ms] compared to a four-syllable delay [mean ± $SD = -58.78 \pm 131.07$ ms; $Z = .31$; ns]. None of the latencies to target words following correct vs. incorrect agreements differed in either temporal window [all p values at least >0.10, according to t tests]. These findings indicate that PNFA patients are insensitive to transitive and thematic agreement violations.

SD patients in the transitive condition did not differ for the "difference score" immediately following a transitive agreement [mean ± $SD = 75.75 \pm 159.27$ ms] compared to a four-syllable delay [mean ± $SD = -36.39 \pm 27.19$ ms; $Z = 1.36$; ns]. None of the latencies to

Table 4
Mean (±*SD*) for the additional language and executive function background tasks by Control Group (Con, $n = 17$), Alzheimer Disease (AD, $n = 15$), Frontotemporal Dementia (FTD overall, $n = 14$), and FTD subgroup (Progressive Nonfluent Aphasia, PNFA, $n = 6$; Semantic Dementia, SD, $n = 6$; Executive/social dysfunction, EXEC, $n = 2$)[a]

	PPT[b] (% correct)	VST[c] (% correct)	TROG[d] (% correct)	TMT Part B[e] (seconds)
Con	94.91 (±2.80)	93.91 (±4.70)	97.97 (±2.13)	108.19 (±72.75)
AD	85.38 (±11.35)	83.75 (±13.75)	92.59 (±8.94)	215.29 (±102.47)
FTD	84.07 (±12.13)	75.60 (±17.30)	87.23 (±10.53)	238.14 (±122.94)
PNFA	82.69 (±15.00)	75.35 (±21.43)	85.83 (±9.95)	273.67 (±134.08)
SD	84.62 (±12.28)	78.47 (±11.31)	88.75 (±11.78)	237.33 (±118.61)
EXEC	86.54 (±2.72)	67.71 (±27.99)	86.88 (±15.03)	134.00 (±82.02)

[a] Group Comparisons: Separate 3 (Group: AD, FTD, Con) × Task One-Way ANOVAs were conducted and are reported by test below. Independent-sample *t* tests show the PNFA and SD subgroups performed equally on all tasks. The EXEC subgroup was not compared due to the small group number.

[b] *Pyramid and Palm Tree Test* (Howard and Patterson, 1992); $F(2,43) = 6.27$, $p < .01$ with the AD and FTD equally less accurate relative to the Control group.

[c] *Verb Similarity Task*—an experimental word task that models the format of the Pyramid and Palm Tree Test; $F(2,43) = 7.44$, $p < .01$ with only the FTD group less accurate relative to Control group.

[d] *Test for the Reception of Grammar* (Bishop, 1989); $F(2,41) = 6.93$, $p < .01$ with only the FTD group less accurate relative to the Control group.

[e] *Trail Making Test*—Part B (Reitan, 1958); $F(2,42) = 7.29$, $p < .01$ with the AD and FTD groups equally slower relative to the Control group.

target words following correct vs. incorrect agreements differed in either temporal window [all *p* values at least >0.10, according to *t* tests]. The SD subgroup also did not differ for the "difference score" immediately following a thematic agreement ($\text{mean} \pm SD = 65.86 \pm 145.04$ ms) compared to a four-syllable delay ($\text{mean} \pm SD = -37.08 \pm 169.19$ ms; $Z = 1.15$; ns). None of the latencies to target words following correct vs. incorrect agreements differed in either temporal window [all *p* values at least >0.10, according to *t* tests]. These findings indicate insensitivity to transitivity and thematic agreements in SD, as well.

An analysis of individual participant performance profiles showed that three of the six (50%) of the PNFA and three of the six (50%) of the SD patients had a greater (violation-correct) discrepancy in their latency to respond to a target word immediately following a transitive agreement compared to the "difference score" following a four-syllable delay. Moreover, three of the six (50%) of the PNFA and five of the six (83%) of the SD patients had a greater (violation-correct) discrepancy in their latency to respond to a target word immediately following a thematic agreement. Although we did not find a significant effect in SD because of the small number of patients and the wide variability in performance, this observation begins to suggest an association between thematic role knowledge in verbs and lexical semantic knowledge that is often impaired in SD.

3.2.4. Correlations between agreement sensitivity and measures of language and executive functioning

Table 4 provides group scores for the additional language and executive background tasks. To improve our understanding of AD and FTD patients' sensitivity to verb roles, we correlated each patient groups' measure of overall agreement sensitivity with measures of language and executive functioning. A summary difference score was created for transitivity sensitivity and thematic sensitivity with the following equation: [Immediate "Difference Score" – Delay "Difference Score"]. Patients who did not complete one or more of the additional cognitive tasks were removed from the analyses. For the AD patients, correlation analyses revealed that sensitivity to the thematic agreement correlated with our experimental 'verb similarity task' ($r = .59$, $p = .02$). No other correlations approached significance. This finding suggests that thematic role knowledge may be important for the understanding of verb meaning. As verb meaning becomes difficult in AD, thematic role knowledge also becomes impaired. For the FTD patients, no significant correlations were seen between verb agreement sensitivity and measures of language and executive functioning.

4. Discussion

Verbs play important roles in sentences. Verbs relay grammatical information such as transitivity—a grammatical role organized around a verb's direct and indirect object use. Verbs also relay semantic information involving thematic roles—such as who can do an action and what type of patient can receive the action. We hypothesized that sentence processing would be differentially compromised in AD and FTD due in part to distinct patterns of impaired processing of thematic and transitive agreements involving verbs. The on-line technique pioneered by Marslen-Wilson and Tyler (1980) allowed us to examine the processing of these two verb agreements while minimizing task-related resource demands. Healthy seniors processed the transitivity and thematic agreements normally. Thus, they were relatively delayed in their detection of a target word encountered in the temporal envelope of processing an agreement violation relative to a coherent agreement.

This difference was not seen when the occurrence of the target word was delayed, consistent with the conclusion that the delay in the immediate vicinity of the agreement violation is due to the processing of the agreement. By comparison, AD patients were impaired at processing the thematic agreements, and FTD patients appeared to be insensitive to transitivity and thematic role agreements. We argue below that impaired thematic role processing in AD may be related to impaired verb semantic knowledge. FTD patients' impairment for both transitivity and thematic role agreements may reflect a broader degradation of verb knowledge that involves both grammatical and semantic representations, or difficulty processing sentence structure that also causes a thematic role deficit.

4.1. Alzheimer's disease and verb comprehension

AD patients, like the healthy seniors, demonstrated intact sensitivity to agreements involving transitivity. However, they did not demonstrate the normal pattern for thematic role agreements. It is unlikely that impaired thematic role agreement sensitivity in AD is due to task-related resource demands, because the on-line comprehension task used to assess verb role sensitivity minimizes executive resource demands needed to perform the task. Moreover, this would not explain AD patients' normal performance for transitivity agreements using the same technique. These findings are consistent with reports that verb thematic information is processed differently from verb transitivity information (Shapiro, Zurif, & Grimshaw, 1987; Shapiro, Zurif, & Grimshaw, 1989). This dissociation instead may indicate that AD patients are selectively impaired comprehending the semantic roles associated with verbs. Previous work has shown that individuals diagnosed with AD are impaired with the thematic, but not grammatical roles, of verbs (Grossman, Mickanin, et al., 1997). This difficulty with semantic information represented in verbs is consistent with the view that individuals with AD have semantic impairments (Chan, Salmon, Butters, & Johnson, 1995; Chertkow & Bub, 1990; Cummings, Benson, Hill, & R., 1985; Glosser, Kohn, Friedman, Sands, & Grugan, 1997; Hodges, Salmon, & Butters, 1990; Nebes, Martin, & Horn, 1984).

Some investigators argue that AD results in a loss of semantic knowledge (i.e., semantic degradation hypothesis). One possibility thus suggests that impaired thematic agreement sensitivity results from semantic network degradation. Although not a universal finding (Fung, Chertkow, et al., 2001; Robinson, Rossor, et al., 1999; Williamson, Adair, Raymer, & Heilman, 1998) many studies have shown that individuals with AD have greater difficulty with verbs than nouns (Bushell & Martin, 2002; Cappa, Binetti, et al., 1998; Robinson, Grossman, et al., 1996; White-Devine et al., 1996). Semantic knowledge associated with verbs may be more susceptible to degradation because it is embedded in a sparser, less redundant and less hierarchically organized semantic matrix than nouns (Levin, 1993). Indeed, some researchers have hypothesized that random damage associated with the disease reduces the redundancy of the semantic network underlying a word, and this may make a word more susceptible to comprehension difficulty in AD (Devlin, Gonnerman, Andersen, & Seidenberg, 1998; Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997). From another perspective, semantic knowledge is said to deteriorate in a bottom-up manner with detailed subordinate concepts lost before superordinate concepts (Chan, Butters, Salmon, & McGuire, 1993; Martin, 1987; Schwartz, Marin, & Saffran, 1979; Warrington, 1975; Weingartner, Kawas, Rawlings, & Shapiro, 1993). Although these studies were based on semantic memory for nouns, the impoverished semantic networks associated with verbs may make these words even more susceptible to degradation. Regardless of the specific nature of the semantic knowledge that is degraded, the observations of the present study may be consistent with degradation of verb thematic role knowledge in AD.

Others argue that the semantic deficit in AD is due to impaired aspects of semantic processing. Specifically, this processing deficit could be due to a deficit of retrieval, such as inhibitory breakdown resulting in competition among semantic nodes thus delaying retrieval, or fast decay of activation that affects the flow of information within the semantic network (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Kolk, 1995). Individuals with AD may perform poorly on tests of semantic knowledge from this perspective because they have deficits in initiating and maintaining organized retrieval strategies (Bonilla & Johnson, 1995; Nebes, Boller, & Holland, 1986; Nebes & Brady, 1990; Nebes, Martin, et al., 1984). Support for this theory has largely come from priming paradigms (Nebes and colleagues). That is, when the effort of a semantic task is reduced to automatic processing (via priming), AD patients are said to perform normally. Problems with this approach include the fact that semantic priming for associative knowledge does not necessarily mean that semantic knowledge is contributing to the association (e.g., Glosser, Friedman, Grugan, Lee, & Grossman, 1998). In this priming study, AD patients primed for lexical associates like "cottage–cheese" but not for semantic category coordinates like "peach–plum." In the current study, we too used a task believed to assess the automatic aspects of language processing (Tyler, Moss et al., 1997), yet still did not observe sensitivity to thematic role knowledge. These findings suggest that the thematic role insensitivity we observed may be due to something other than this kind of processing impairment.

Another possible account for impaired thematic role sensitivity in AD is concerned with the categorization processes needed for verb comprehension. This model of semantic memory proposes two components: Semantic feature representations; and processes such as categorization that make use of this knowledge for semantic decisions. There are several types of categorization processes. One type is 'rule-based.' This process evaluates word meaning relative to a set of diagnostic criteria. From this perspective, the thematic role of a verb is evaluated in a rule-like manner with reference to a set of features representing the verb's meaning (Grossman, Smith, et al., 2002, 2003). Selective attention identifies the relevant features; inhibitory control manages irrelevant features; and the criteria must be kept active in working memory while working memory is up-dated to keep track of the results of the evaluation. Evidence to support this approach comes from categorization judgments of brief object descriptions. However, these did not involve verbs or their associated thematic roles. There was no correlation between executive background tasks and sensitivity to thematic role violations in AD patients in the current study, moreover, suggesting that this model may be more appropriate for representations of concepts rather than verb-mediated agreements in sentences.

An alternative processing theory is that individuals diagnosed with AD have semantic difficulty due to a failure to inhibit competing associates (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1979). According to these researchers, efficient semantic processing requires the ability to inhibit competing semantic associates that become active during semantic processing. These researchers postulate that there is a breakdown in inhibition at the semantic network level in AD that results in an extended search time associated with long reaction time latencies for both correct and incorrect associates. Such would fit a proposed model of thematic role processing described by Shapiro and Levine (1990). This model states that all of a verb's thematic possibilities are activated when a verb is encountered. The thematic processor then assigns thematic roles to noun phrases as they are encountered in real-time. According to this theory, if AD patients activate all of the thematic matrix possibilities and at the same time they suffer from inhibitory breakdown, then the search process should be more effortful and result in extended reaction time latencies for both correct and incorrect associates. Although an intriguing possibility, data from the current investigation are not consistent with this theory. We found that the reaction time latency at the four-syllable time window for the AD patients is not significantly different from that of the control participants. This suggests that the AD patients are not engaged in a prolonged semantic search process. Additionally, there was no correlation between executive processing and thematic violation sensitivity—a finding that could have been supportive of the theory that semantic processing is related to inhibitory semantic demands.

Fast decay of activation in the semantic network may also be influencing AD patient sensitivity to the thematic role agreements. Kolk and Van Grunsven (1985) originally posed the concept of fast decay to explain variations in processing among agrammatic patients. According to Kolk (1995), two changes to the normal processing situation are possible. First, slow activation can occur in that it takes longer for an element to reach its critical level of activation. Second, fast decay may occur which makes elements unavailable because they fall below their critical level of activation too soon to be combined with other elements in the sentence representation. The current study did not observe slow activation in processing thematic information. Thus, possibly the failure to process thematic roles is associated with rapid decay of activation. More work investigating the possibility of fast decay in semantic networks in AD patients is needed to evaluate this account of impaired thematic role knowledge.

Regardless of the cognitive processes explaining thematic role difficulty in AD, the semantic component of verb meaning may also be associated with a particular anatomic distribution of disease in these patients. While there has been no work assessing the neural basis for verb thematic roles in AD, a recent fMRI study investigated the neural basis of verb meaning in AD relative to healthy seniors (Grossman, Koenig, et al., 2003). Patients were asked to judge the "pleasantness" of a verb, including verbs of motion and verbs of cognition. Both healthy seniors and AD patients activated the left posterolateral temporal region across both semantic categories. However, a direct comparison revealed significantly reduced activation in this area in AD relative to healthy seniors. Activation was instead displaced to an adjacent region. A similar activation pattern was also seen for nouns (Grossman, Koenig, et al., 2003). The authors stated that this reduced and displaced activation may be due to the histopathological distribution of the disease in left posterolateral temporal cortex in AD. Other work has implicated left posterolateral temporal cortex in lexical–semantic processing in structural imaging studies of patients with damage to this region (Chertkow, Bub, Deaudon, & Whitehead, 1997; Hart & Gordon, 1990; Hillis, Wityk, & Tuffiash, 2001). Correlations of cortical atrophy with lexical semantic judgments of nouns/objects in AD have implicated left temporal–parietal cortex as well (Baron, Chetelat, et al., 2001).

The data from the current investigation thus are consistent with a larger picture suggesting that verbs play multiple roles in sentence processing, and observations of AD patients suggest that some of these roles are dissociable. Because the AD patients can comprehend transitivity, it is clear that they have an understanding of at least one component of a verb. In contrast, they have difficulty processing a verb's thematic roles. There is much speculation about the precise basis for this impairment, but additional work is needed to determine whether this is related to degradation of verb thematic role knowledge or a deficit in processing this component of a verb.

4.2. Frontotemporal dementia and verb comprehension

The pattern of performance in FTD differs from that seen in AD. Unlike AD, we did not observe sensitivity to thematic or transitive agreements in FTD. This was despite the relatively automatic nature of the on-line task. FTD patients' impairment thus cannot be attributed easily to task-related resource demands. There was also no evidence of slowed processing, and we found no correlation between agreement sensitivity and executive and language comprehension abilities.

Verb naming and comprehension appears to be impaired in FTD. Cappa, Binetti, et al. (1998) reported that both AD and FTD patients were more impaired with action naming relative to object naming. However, the discrepancy between object and action naming was significantly greater in FTD than in AD. Rhee, Antiquena, et al. (2001) reported that FTD patients are more impaired for verbs than nouns on a picture-word matching task. This study showed different patterns of comprehension difficulty in PNFA and non-aphasic patients with an executive disorder. The PNFA patients' comprehension of verbs may have been related to degraded verb knowledge since concurrent performance of a secondary task did not worsen their performance further. Bak et al. also suggested that the neural representation of verb knowledge is degraded in some FTD patients (Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001). In the present study, we tried to determine whether there were consequences of this for verb agreements during sentence processing. In fact PNFA patients appeared to be broadly impaired in processing verb transitivity and thematic role agreements. It is important to note that there is some variability in PNFA patients' performance, with some patients showing grammatical difficulty and others presenting primarily with dysarthria (Thompson, Ballard et al., 1997). It may be that individual differences such as these masked significant effects in FTD, and we were unable to bring out effects within the PNFA patient subgroup because of the small number of patients. Although we know less about verbs in SD, there is much evidence suggesting that SD patients have degraded knowledge of individual word meanings (Hodges, Graham, & Patterson, 1995; Hodges, Patterson, Oxbury, & Funnell, 1992, 1994; Lambon Ralph, Graham, et al., 1998; Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001; Snowden, Goulding, & Neary, 1989). The finding that PNFA patients and SD patients had similar patterns of impairment may indicate that there is a single form of Primary Progressive Aphasia, where different aspects of language difficulty emerge at different points in the course of the condition (Karbe, Kertesz, & Polk, 1993; Mesulam, 2001; Mesulam, Grossman, Hillis, Kertesz, & Weintraub, 2003) However, this is difficult to determine based on the small number of patients participating in this study. Additional work is necessary to determine the role of verb difficulty in the sentence processing deficits of FTD patients.

An alternate possibility is that processing verb knowledge in a sentence could be due to independent deficits involving each subcomponent of a verb, rather than degradation of all verb-associated knowledge, and that the deficit in both verb components is due to the dependence of one verb component on the other. An impairment in transitivity in FTD could be due to degradation within the grammatical system (Grodzinsky, 1986, 1990, 1995), or there could be a failure to process grammatical knowledge for the purpose of understanding a sentence (Frazier & Friederici, 1991; Kolk, 1995; Swinney & Zurif, 1995; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). Transitivity is an example of a core structure-building device necessary to support sentence comprehension (Grodzinsky, 1986, 1990, 1995; Shapiro & Levine, 1990). For example, transitivity signals whether a verb requires a direct or indirect object. From this perspective, transitivity provides a structure for the semantic mapping of thematic roles, and a deficit appreciating transitivity agreements thus may hinder the processing of thematic roles. It may be that appreciation of thematic role agreements is itself not impaired, but rather its dependence on transitivity structure may result in impaired thematic role processing. Grodzinsky (1995) proposes, for example, that the structural traces that link thematic roles to the grammatical referent of a verb can be lost or "deleted." Insensitivity to thematic roles thus could involve a decay of the verb's trace that would limit reactivation of the agent role's node following processing of the verb. Alternately, there could be an impairment in verb processing such that grammatical structure information does not remain active long enough to allow processing of transitivity or mapping of thematic roles (Frazier & Friederici, 1991; Kolk, 1995; Swinney & Zurif, 1995; Zurif, Swinney, et al., 1993).

4.3. Study limitations

There are shortcomings associated with this study that must be kept in mind when interpreting our findings. First, the study assessed patients with mild to moderate disease severity, and the results should be generalized with caution to other AD and FTD cohorts. Second, the diagnosis in these patients has not been validated at autopsy. Although our clinic has histopathologic confirmation of AD and FTD in many patients resembling those who participated in this study, the diagnosis of FTD and AD has been based on clinical evaluation confirmed by structural and functional imaging investigations. Third, the small sample size of the patient samples and, in particular, the FTD subgroups may have contributed to insensitivity of the on-line task. Finally the word detection task is not entirely free of resource demands since divided attention is needed to detect a target word while listening to a sentence for comprehension.

With these caveats in mind, the current study demonstrates that verb agreement processing is compromised in AD and FTD. Comprehension of thematic role agreements, but not transitivity agreements, is impaired in AD. This may be related to their broader semantic deficit. FTD patients, in contrast, were insensitive to both thematic and transitivity agreements. This may be associated with a broad-based degradation in verb knowledge, or difficulty with structure-building that also impaired comprehension of thematic roles in a sentence.

Appendix A

Thematic condition*

The [chickens/jokes] appear *quickly* from behind…
The [trains/houses] bring *charcoal* to the tiny…
The [buckets/colors] capture *nearly* every drop…
The [lizards/feathers] cling *next* to the cage…
The [trucks/brushes] compress *rotten* smelly *bags...*
The [turtles/birds] crawl *through* dry grass toward…
The [vines/acorns] creep *beside* the old…
The [radar/desk] detects *changes* in motion…
The [stars/rocks] emerge *between* clouds on clear…
The [plaster/thought] falls *onto* the carpet…
The [teacher/tree] gazes *away* from disabled…
The [plumber/pillow] injects *bright* yellow liquid…
The [worker/cow] installs *gray* bricks with black…
The [duck/snake] limps *toward* every person…
The [police/fires] listen *closely* from behind…
The [chef/sauce] mashes *buckets* of overly…
The [academies/lights] mold *ladies* into national…
The [eagle/flame] notices *movement* on the canyon…
The [wind/robber] peeks *into* the room through…
The [owl/rain] peers *beneath* old maple tree…
The [butler/table] perceives *problems* with many…
The [waiter/chair] put *cheese* samples near…
The [submarines/sponges] rescue *dolphins* and other…
The [roaches/snails] scurry *loudly* across this kitchen…
The [thermometer/curtain] senses *minor* changes between…
The [student/soup] slumps *onto* the table…
The [arrow/worm] soars *through* the trees into…
The [butcher/lion] sorts *red* meat from behind…
The [fireman/fountain] stumbles *across* the threshold…
The [passengers/blankets] view *movies* during cross…

Transitive Condition*

The bugs [appear/appear water]*nightly* under porch…
The hamster [brings/brings beside] *chewed* carrot chips…
The bubbles [cling/cling food] *with* cold water around…
The girls [compress/compress through] *dough* using large…
The child [crawls/crawls grass] *through* mud and leaves…
The convicts [creep/creep dusk] *nightly* into local…
The device [detects/detect into] *tide* levels and changes…
The tadpoles [emerge/emerge caves] *brown* and very muddy…
The clown [gazes/gazes face] *toward* the circus building…
The artist [injects/injects within] *rust* colored ink…
The salesman [installs/installs behind] *new* and antique kitchen…
The donkey [limps/limps straw] *toward* water buckets…
The jury [listens/listens lawyer] *quietly* for more…
The children [mash/mash within] *rocks* into the dry…
The reporters [mold/mold toward] *boring* town events…
The travelers [notice/notice along] *angry* country natives…
The mouse [peeks/peeks cheese] *bravely* through bedroom…
The machines [peer/peer light] *inside* small dark…
The researchers [perceive/perceive within] *changes* in the *ocea*n…
The secretary [puts/puts around] *coffee* stains along…
The navy [rescues/rescues within] *injured* baby black…
The crab [scurries/scurries sand] *through* the iron pipe…
The twins [sense/sense toward] *exciting* and traumatic…
The cowboy [slumps/slumps walls] *behind* the old…
The ball [soars/soars dirt] *beyond* the crowded…
The king [sorts/sorts in] *rare* Asian jade…
The horses [stumble/stumble rock] *along* the newly…
The strangers [view/view onto] *ocean* seafood markets…

*[ ], brackets contain the correct and incorrect agreements. *Italicized* words, target word used for the immediate position. *Underlined* words, target words used for the delay position. Each sentence ended after the participant identified the target word.

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