

Syntactic and thematic components of sentence processing in progressive nonfluent aphasia and nonaphasic frontotemporal dementia

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Received 2 March 2007; received in revised form 27 April 2007; accepted 27 April 2007

Abstract

We used an online word-monitoring paradigm to examine sentence processing in healthy seniors and frontotemporal dementia patients with progressive nonfluent aphasia (PNFA) or a nonaphasic disorder of social and executive functioning (SOC/EXEC). Healthy seniors were sensitive to morphosyntactic, major grammatical subcategory, and selection restriction violations in a sentence. PNFA patients were insensitive to grammatical errors, but showed reasonable sensitivity to thematic matrix violations, consistent with a differential grammatical processing impairment. By contrast, SOC/EXEC patients showed partial sensitivity to grammatical errors but were insensitive to thematic violations. These findings support a dissociation between grammatical and thematic components of sentence processing. Specifically, they are consistent with a grammatical processing deficit in PNFA patients, and impairment in the formation of a coherent thematic matrix in SOC/EXEC patients.

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Keywords: Frontotemporal dementia; Progressive aphasia; Syntax; Grammar; Thematic matrix; Sentence comprehension

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1. Introduction

Comprehending a sentence is a complex task supported by multiple processing components. These include, at minimum, the representation of rules that define dependencies between words in a sentence and the executive resources required to process these relationships during sentence comprehension. In the present study, we seek converging evidence regarding components of sentence processing through an online study of sentence comprehension in patients suffering from a focal neurodegenerative disease.

Evidence from ERP studies supports the existence of multiple stages of syntactic analysis during sentence comprehension (Friederici, 1995, 1998). First-pass parsing is evident at approximately 200 ms in an early left anterior negativity, and is modulated by morphosyntactic errors involving omission of the past tense inflection (e.g., *John kick Jack*) and violations of major grammatical subcategories, such as substitution of a noun for a verb (e.g., *John foot Jack*). Detection of these errors is associated with relatively automatic syntactic structure-building processes (Friederici, 1995; Hahne & Friederici, 2002; Mecklinger, Shriefers, Steinhauer, & Friederici, 1995). Second-pass parsing is seen around 400 ms in two dissociable distributions, responding to semantic anomalies (Kutas & Hillyard, 1980) and selection restriction errors that violate the relationships determined by a verb's thematic matrix (Friederici, 1998; Rösler, Pütz, Friederici, & Hahne, 1993). Finally, a third component with wide positive bilateral posterior distribution is related to structural reanalysis (Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994). This multi-stage model of sentence processing is also supported by reaction time studies to coherence judgments of sentences, which find slower responses to semantic and thematic violations than to syntactic errors (Fodor, Ni, Crain, & Shankweiler, 1996; McElree & Griffith, 1995).

Efforts have been made to determine the neuroanatomical bases for these stages of processing. A long history of stroke research has implicated regions of the inferior frontal cortex (IFC) in syntactic processing (Zurif, 1996; Zurif & Caramazza, 1976; Zurif, Caramazza, & Myerson, 1972). Consistent with these data, evidence obtained from fMRI in healthy young adults also attributes important aspects of sentence processing to IFC. Activation in IFC is reliably seen during a wide variety of tasks that probe grammatical aspects of a sentence (Ben-Shachar, Palti, & Grodzinsky, 2004; Caplan, Alpert, & Waters, 1998; Cooke et al., 2002; Heim, Opitz, & Friederici, 2003; Kang, Constable, Gore, & Avrutin, 1999; Ni et al., 2000; Peelle, McMillan, Moore, Grossman, & Wingfield, 2004), although the precise location of this activation depends on the nature of the stimuli and task demands (Kaan & Swaab, 2002). Some authors conclude that inferior frontal activation specifically supports grammatical structure-building (Ben-Shachar et al., 2004; Caplan, Alpert, Waters, & Olivieri, 2000; Ni et al., 2000), whereas others hold that it also reflects executive resources required for sentence processing (Cooke et al., 2006, 2002; Grossman et al., 2002).

Functional neuroimaging studies also associate frontal recruitment with the detection of grammatical and thematic errors, although there appear to be subtle but important factors dissociating these sentence processing components within the frontal lobe. In one study, similar inferior frontal regions were activated in different ways depending on the nature of the error (Kuperberg et al., 2003), although other studies have found that the anatomic distribution of activation differs depending on the type of error (Newman, Pancheva, Ozawa, Neville, & Ullman, 2001; Newman, Just, Keller, Roth, & Carpenter, 2003). For

example, Newman et al. (2003) related pars opercularis of left IFC to the detection of a grammatical error and pars triangularis to detecting a thematic violation. Passive listening to brief sentences results in inferior frontal activation during presentation of grammatical errors and anterior as well as posterior activation during presentation of thematic errors (Ni et al., 2000). Taken together, this work indicates that left IFC contributes to the detection of several types of errors in a sentence.

To obtain converging evidence regarding the neuroanatomy of sentence comprehension, we compared sentence processing in healthy adults to that in two groups of patients with frontotemporal dementia (FTD), a family of neurodegenerative conditions affecting the frontal and temporal lobes (Grossman, 2002). We studied sentence processing in patients classified as belonging to one of two distinct phenotypes in order to provide additional evidence regarding the involvement of frontal cortex in language processing. Although cortical atrophy in these patients can be varied, relatively consistent stereotypical patterns of atrophy exist for each subgroup, which may suggest neuroanatomical bases for observed behavioral impairments.

The first subgroup of FTD patients we studied was diagnosed with progressive nonfluent aphasia (PNFA). PNFA is associated with atrophy to the left IFC and nearby regions such as anterior insula, dorsolateral prefrontal cortex, frontal operculum, and anterior superior temporal cortex (Gorno-Tempini et al., 2004; Grossman et al., 2004, 1996; Nestor et al., 2003). It is characterized by effortful and agrammatic speech which is often dysarthric and contains phonemic paraphasic errors (Grossman, 2002). PNFA patients often have difficulty understanding grammatical aspects of sentences (Grossman & Ash, 2004; Grossman et al., 1996; Snowden, Neary, Mann, Goulding, & Testa, 1992; Thompson, Ballard, Tait, Weintraub, & Mesulam, 1997).

The second subgroup of FTD patients we studied were diagnosed with a disorder of social and executive functioning (SOC/EXEC). Frontal atrophy in SOC/EXEC patients tends to be more right lateralized, and does not typically involve inferior frontal regions affected in PNFA (Grossman et al., 2004; Rosen et al., 2005, 2002; Williams, Nestor, & Hodges, 2005). SOC/EXEC patients demonstrate a wide variety of limitations in executive resources such as working memory, strategic planning, selective attention, inhibitory control, and organization (Boone et al., 1999; Libon et al., 2007; Rahman, Sahakian, Hodges, Rogers, & Robbins, 1999; Razani, Boone, Miller, Lee, & Sherman, 2001). Despite the lack of aphasic presentation, SOC/EXEC patients' executive limitations have been demonstrated to influence language processing. For example, SOC/EXEC patients have difficulty with working memory aspects of sentence processing (Cooke et al., 2003), and their working memory difficulty correlates with difficulty organizing the elements of a narrative (Ash et al., 2006). In a lexical acquisition task, SOC/EXEC patients did not differ statistically from controls in their processing of grammatical or semantic information associated with a new verb, but were significantly impaired in processing the new verb's thematic relations (Murray, Koenig, Antani, McCawley, & Grossman, 2007). This suggests that the executive resource limitations faced by SOC/EXEC patients interfered with their ability to integrate grammatical and semantic sources of information into a coherent thematic matrix.

Although the studies noted above have proven informative in characterizing language difficulties in FTD, they share a weakness in that they use offline measures to assess language function. In addition to sentence processing, such measures also reflect resources related to performance of the offline task (e.g., recall). A small number of studies have

begun to address this issue by using online measures of sentence processing to assess sentence comprehension in FTD (e.g., Grossman, Rhee, & Moore, 2005; Tyler, Moss, Patterson, & Hodges, 1997). In the word detection procedure employed by these studies (Marslen-Wilson & Tyler, 1980), a target word is given to participants, who are then instructed to press a button when the target is heard in a following sentence. When the target word closely follows an error in the sentence, normal processing is disrupted, resulting in longer latencies to respond to the target word. By varying the distance between the violation and target word, the temporal duration of the effect can also be ascertained.

This technique can also be used to demonstrate insensitivity to particular violations—indicative of impaired processing—observed in various patient populations. A recent study of sentence comprehension in FTD tested online sentence comprehension in this manner using sentences that contain errors in grammatical agreement (Grossman et al., 2005). These included quantifier (Q-float) agreements (e.g., *The child can each take one cookie from the jar*), determiner-noun agreements (e.g., *This books will not be easy for boys to read*), and subject-verb pluralization agreements (e.g., *The radio are too loud to play on the train*). With these complex constructions, PNFA patients were shown to be insensitive to grammatical components of a sentence immediately following a target word, but demonstrated sensitivity in a prolonged processing window following the error. This suggests delayed grammatical processing, and possibly the loss of information maintained in working memory during the course of processing. Nonaphasic SOC/EXEC patients resembled healthy adults, underscoring their relatively preserved grammatical processing.

In the present study we make use of the same word-monitoring technique to assess online sentence comprehension in PNFA and SOC/EXEC patients relative to healthy seniors. We sought to extend knowledge regarding sentence processing in PNFA and SOC/EXEC patients by employing sentences containing different classes of errors than previously studied: morphosyntactic errors involving past tense formation, grammatical word class errors involving substitution of a noun for a verb, and selection restriction violations. We expected that the PNFA patients would demonstrate relative insensitivity to the grammatical errors present in these sentences. We also investigated whether SOC/EXEC patients would have difficulty processing thematic relations, as suggested by Murray et al. (2007).

2. Method

2.1. Participants

We studied 13 patients diagnosed with FTD in the Department of Neurology at the Hospital of the University of Pennsylvania. The diagnosis of FTD was established by an experienced neurologist according to published criteria (The Lund and Manchester Groups, 1994; McKhann et al., 2001). This included primary progressive aphasia or a disorder of personality and social comportment with executive difficulty. Patients with other forms of dementia were excluded. The patients and their legal representatives participated in an informed consent procedure approved by the IRB at the University of Pennsylvania.

We analyzed performance of two subgroups of FTD patients, divided according to their clinical presentation. Subgroup classification was established by the application of defined

criteria in a consensus conference based on the review of a semi-structured history, mental status exam, and neurological exam by at least two independent, trained reviewers. If the reviewers disagreed in their diagnosis, consensus was established through discussion. The subgroups were based on published criteria (Neary et al., 1998) that have been modified to improve reliability (Davis, Price, Moore, Campea, & Grossman, 2001; Price, Davis, Moore, Campea, & Grossman, 2001). The first subgroup of FTD patients consisted of those presenting with PNFA ($n = 6$). These patients had the insidious onset of effortful speech with phonemic paraphasias that may have been associated with dysarthria and impaired sentence comprehension, but relatively good single word comprehension. The second subgroup of patients presented with a disorder of executive functioning such as poor planning, selective attention, and organization often accompanied by social and behavioral difficulties such as an impairment in social interpersonal conduct and regulation of personal conduct, emotional blunting and loss of insight (SOC/EXEC; $n = 7$). Although there was no clinical evidence for a true language deficit, as spontaneity or a disorder of discourse may have been observed.

Demographic characteristics for all participants are summarized in Table 1, which also summarizes performance on several representative neuropsychological measures. Data for the Tokens task and the Oral Symbol Digit task are not reported for two PNFA patients and one SOC/EXEC patient because they were obtained more than 6 months away from the experimental protocol. PNFA patients tended to perform more poorly on an auditory sentence comprehension task, while SOC/EXEC patients performed more poorly on tests of executive functioning that measure planning and inhibition, although due to the modest group sizes these differences were not significant. In addition to the FTD patients we also tested a total of 20 healthy right-handed native English-speaking seniors. These healthy senior participants matched FTD patients in age [$t(35) = 0.10$, *n.s.*], and matched SOC/EXEC patients in their education [$t(25) = 1.20$, *n.s.*]. PNFA patients were not as well educated as the healthy seniors [$t(23) = 3.41$, $p < .005$], and slightly less educated than SOC/EXEC patients, although this effect did not reach significance [$t(11) = 1.95$, *n.s.*]. All participants were tested by the same group of researchers using identical materials.

Table 1
Mean (\pm standard deviation) demographic features and neuropsychological scores

Measure	Seniors ($n = 20$)	SOC/EXEC ($n = 7$)	PNFA ($n = 6$)
Age (yr)	65 (11.0)	60 (10.4)	71 (7.2)
Education (yr)	16.2 (2.9)	14.6 (3.2)	12.6 (1.5)
MMSE (max = 30)	29 (1.6)	24 (5.1)	25 (3.6)
Trails B (% correct)	96 (3.5)	91 (9.6)	88 (8.9)
Oral Symbol Digit (% correct)	98 (2.8)	78 (43.6)	92 (5.4)
Tokens (% correct)	92 (8.3)	83 (10.2)	71 (83.4)

Note: Oral Symbol Digit is a test of executive function in which participants are given a written “code” that matches numbers to a geometric symbol, then given a series of symbols and are asked to provide the number that matches the symbol as quickly as possible in 90 s. Trails B is a test of executive function in which participants are given a paper with letters and numbers distributed randomly across the page, and are asked to connect these stimuli with a pencil in ascending order alternating numbers and letters during a 300 s trial. “Tokens” is an untimed test of auditory sentence comprehension in which participants are given a sequence of commands to move several geometric shapes that are in different colors.

Table 2
Examples of sentence stimuli

Error type	Example sentence
Thematic	The President is being <i>*spiced/honored</i> proudly in the peaceful country in eastern Africa
Morphological	The book is being closely <i>*pick/picked</i> by the large group of curious students
Word class	The friend is being <i>*reunion/met</i> near the big statue by the shopping mall

Note: Examples of both correct and erroneous (marked with an *) sentences versions are given.

2.2. Materials

We evaluated processing of sentences containing three types of errors modeled after Friederici (1995). Examples of these stimuli are listed in Table 2. The “morphological” items contain a morphosyntactic error, where the morpheme “-ed” denoting a past participle is omitted. The “word class” items contain substitutions of major grammatical word class, where a noun related in meaning to the semantic context of the sentence is substituted for a verb. We grouped these two agreements together for the purpose of the initial analyses described below into a “syntactic” error. The “thematic” sentence subtype contains violations of selection restriction in which constraints of meaning associated with a verb such as an allowable agent were violated.

Each sentence contained 13 words. Target words were placed in one of two positions following a targeted sentence component. In the “early” position, the target immediately followed the sentence component of interest; in the “late” position, the target word was placed seven words after the sentence component. For each of these positions, we presented equal numbers of correct sentences and sentences with errors. Preliminary studies used a cloze procedure to reduce the possibility of participants predicting the occurrence and position of the target sentence element. When a target word was a member of several major grammatical categories in the “word class” condition, we ensured that its frequency of occurrence was at least seven times greater for the intended grammatical subcategory compared to the secondary word subcategory. Sentence types were distributed over two pairs of counterbalanced blocks that were presented in a random order across participants. One block containing a correct version of a sentence was paired with another block containing a version of the same sentence with a violation. A total of 480 sentences were used: one-quarter of the sentences were experimental items, half correct and half containing a violation, and these were equally divided among the three types of errors. Three-quarters of the presented sentences in each block were filler items, and half of these items contained an error. Reaction times to these filler items were not analyzed.

Sentences were recorded by a female native English speaker at a comfortable speaking rate. Participants heard sentences over binaural headphones at a comfortable listening level that, once set, remained unchanged for the duration of the experiment.

2.3. Procedure

Participants were informed that they would hear a word followed (1000 ms later) by a beep, and then (1000 ms later) a sentence would be heard that contains the same word. If

needed, the experimenter repeated the target word. Participants were not informed that some of the sentences would contain an error. They were asked to press the space bar of the computer as soon as they heard the target word in the sentence. The button press interrupted the sentence, and initiated the next item after 1500 ms. To ensure that participants were attending to the sentence stimuli, 8 questions probing the content of a correct sentence were randomly distributed throughout each block. Participants were warned that presentation would be occasionally interrupted and they would be asked a content-related question about a sentence. A brief practice test that included correct sentences and sentences with errors was administered to familiarize the participants with the task. Participants were allowed to rest between blocks as desired, and at times the second block was administered to FTD patients on a different day within a month in order to minimize fatigue. Blocks were administered in a random order.

All sentences were presented by PsyScope presentation software (Cohen, MacWhinney, Flatt, & Provost, 1993), which also recorded response latencies to target words, timed from the onset of the target word. Analyses of latency data were conducted after extreme outliers had been eliminated (responses occurring <100 ms or > 10 000 ms after a target word), and a two standard deviation filter relative to each subject's average response latency was implemented. We replaced these items with each subject's average latency.

3. Results

Response latencies for target words in correct sentences and those containing an error are shown in Table 3. To establish an overall effect of syntax, we collapsed across the two types of syntactic errors for some analyses. We used a mixed-model analysis of variance (ANOVA) to analyze performance, using group (3: seniors, SOC/EXEC, PNFA), error type (2: syntactic, thematic), error status (2: correct, violation), and position (2: early, late) as factors. This analysis yielded a significant four-way interaction effect [$F(4, 60) = 2.87, p < 0.05$], consistent with our predictions of differential language processing abilities among the three groups of participants. We used *t*-tests to establish the basis for

Table 3
Mean latencies to respond to target words

		Thematic		Syntactic					
				Average		Morpheme		Word class	
		Correct	Error	Correct	Error	Correct	Error	Correct	Error
Seniors	Early	666	728*	598	677*	554	602*	642	752*
	Late	608	693*	661	594	740	664	582	524
PNFA	Early	1361	1494 ⁺	1257	1320	1171	1222	1342	1418
	Late	1130	1086 ⁺	1096	853	1247	884	944	822
SOC/EXEC	Early	1524	1294	1190	1304 ⁺	1139	1032	1240	1577**
	Late	1236	1194	1042	1068	1043	1142	1040	993

Note: * Indicates a significant group effect ($p < .05$); ** indicates a marginally significant group effect ($p < .08$); ⁺ indicates that a majority of individual patients show the group effect even though a significant group effect is not found.

this effect. Because our small sample sizes were vulnerable to influence from one or two patients, we also examined effects on a patient-by-patient basis for the SOC/EXEC and PNFA groups.

We first analyzed participants' performance to syntactic items, averaged across word-class and morphological violations. Healthy seniors' relatively intact syntactic processing was evident in their sensitivity to syntactic violations, which resulted in increased latencies to target word responses during the early time window relative to control sentences [$t(19) = 5.94, p < 0.001$]. Consistent with syntactic processing difficulties experienced in PNFA, the PNFA patients in our study did not show any sensitivity to the syntactic violations tested here. Although SOC/EXEC patients' responses were generally longer than that of the healthy seniors, 86% (6/7) showed a significant sensitivity to syntactic violations in the early time window.

We next examined the two types of syntactic violations separately. In healthy seniors, latencies to respond to early targets in sentences were significantly longer when they contained a morphological error [$t(19) = 2.94, p < 0.01$] or a word class error [$t(19) = 5.67, p < 0.001$], relative to control sentences. By comparison, there was no significant difference in PNFA patients' responses to early targets in sentences with a morphological error or a word class error [$t(5) < 1, n.s.$]. In SOC/EXEC patients, we observed a difference in latency to respond to early targets in sentences with a word class substitution error compared to control sentences at a level that approached significance [$t(6) = 2.13, p < 0.08$]. Six (86%) of the EXEC patients displayed this trend. SOC/EXEC patients did not show a longer latency for the morphosyntactic error compared to control sentences.

Healthy seniors were sensitive to a selection restriction violation, demonstrating longer latencies to respond to a target word following a selection restriction violation compared to control sentences when the target word was in either the early position [$t(19) = 2.55, p < 0.01$] or late position [$t(19) = 2.47, p < 0.05$]. This is consistent with behavioral and ERP findings suggesting that the detection of a selection restriction violation involves both a rapid, automatic component and a component that extends later in time.

The PNFA patients' performance on sentences containing thematic violations was somewhat variable. Although there was not a significant group effect, four of the six patients (67%) exhibited the normal pattern of longer latencies for a thematic agreement error compared to a correct sentence in both early and late time windows. This is consistent with our hypothesis that for most PNFA patients thematic processing is relatively intact. By contrast, there was no indication that SOC/EXEC patients were sensitive to thematic violations. This was supported by a lack of a significant group effect [early: $t(6) = 1.97, n.s.$; late: $t(6) < 1, n.s.$] and the absence of a consistent trend. This finding may reflect in part the cognitive resource limitations in SOC/EXEC patients.

4. Discussion

This study assessed the integrity of grammatical processing in FTD patients using an online paradigm that minimizes task-related resource demands. We demonstrated that PNFA and SOC/EXEC subgroups have different patterns of impaired sentence processing. These observations are consistent with the multi-factorial nature of sentence comprehension difficulty in FTD, and emphasize the complexity of the processes contributing to successful sentence comprehension. We discuss below the performance of healthy seniors, followed by a consideration of each FTD subgroup.

4.1. Sentence processing in healthy seniors

Comparable to a previous study involving young adults (Cooke et al., 2006), healthy seniors demonstrated sensitivity to grammatical and thematic errors in a sentence. That is, within the temporal processing envelope that immediately follows a grammatical or thematic process, healthy seniors showed a relative delay in responding to a target word following an error compared to a target word placed at the same point of a correct sentence. This was true for selection restriction violations as well as morphosyntactic errors and word class substitution errors. When the target word was located at a delay following a grammatical agreement, control participants no longer showed a difference between target word detection following a grammatical violation compared to a correct sentence. This indicates that the syntactic processes involved in mediating a grammatical agreement have completed by the time that the target word is encountered.

The processes mediating sensitivity to selection restriction violations have a different temporal profile, demonstrating a late component that extends over time. This is evidenced by the healthy seniors' sensitivity to thematic violations in both the early and late time windows, and is consistent with reaction time studies to coherence judgments of sentences that find slower responses to semantic and thematic violations than syntactic errors (Fodor et al., 1996; McElree & Griffith, 1995).

4.2. Sentence processing in PNFA

The majority of PNFA patients were sensitive to thematic violations in the current study, supporting largely preserved thematic processing in this patient group. Consistent with previous findings, however, PNFA patients were not sensitive to either class of syntactic error (morphosyntactic or word class substitution errors). One possible explanation is that the rule governing regular verb morphological processing (adding “-ed” to the citation form of the verb) is degraded or cannot be processed in these patients (Ullman, 2004; Ullman et al., 1997), although other data conflicts with this interpretation (Ash, Koenig, Moore, & Grossman, submitted; Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003; Patterson, Lambon Ralph, Hodges, & McClelland, 2001).

An alternate account implicates grammatical processing deficits (rather than degraded knowledge) in PNFA patients' relative insensitivity to specific grammatical features of a sentence. The grammatical processing deficit in PNFA appears to be related to left IFC: MRI studies of PNFA show gray matter atrophy in an inferior frontal distribution (Grossman & Ash, 2004; Grossman et al., 2004; Nestor et al., 2003), and difficulty with sentence processing in PNFA has been linked to reduced activity in inferior frontal and anterior superior temporal portions of the left hemisphere using both PET (Grossman et al., 1996; Nestor et al., 2003) and SPECT (Grossman et al., 1998). In an fMRI activation study of PNFA, we found reduced activation of ventral portions of left IFC during attempts to understand grammatically challenging aspects of a sentence (Cooke et al., 2003). The vulnerability of the ventral inferior frontal region in PNFA may explain in part the difficulty these patients encounter with syntactic structures. In an fMRI study of healthy young adults using the materials from the present study, we observed activation of the ventral portion of left IFC during the detection of these grammatical features (Cooke et al., 2006). Although the comprehension of a sentence's grammatical properties may not be identical to the detection of a grammatical error, these observations nevertheless suggest

that PNFA patients have difficulty detecting grammatical errors in a sentence because of a selective deficit for the processes involved in appreciating these features of a sentence. These findings must be confirmed with additional work because of the small number of these rare patients participating in the current study.

In a previous study using the same online word detection procedure as the current study but with different types of errors, PNFA patients demonstrated sensitivity to a grammatical error, but only in a delayed temporal processing window (Grossman et al., 2005). However, comparisons between this previous study and the current data are difficult. First, the previous study of sentence processing in PNFA used different types of violations than those presented here. Second, the previous study used a four-syllable separation for the “late” processing window, compared with seven words in the current study. Thus, although more research is required to determine the precise nature of grammatical deficits in PNFA patients, together these two studies are consistent in showing PNFA patients’ grammatical impairment. This impairment is reflected by an inability to detect syntactic errors, as in the current study, or a significantly delayed processing of these errors.

4.3. Sentence processing in SOC/EXEC patients

SOC/EXEC patients had difficulty processing selection restriction violations. This resembles SOC/EXEC patients’ performance during acquisition of a new verb, in which SOC/EXEC patients were significantly impaired in their acquisition of thematic matrix information such as selection restriction properties of the agent, despite their adequate grammatical and semantic performance (Murray et al., 2007). We believe that SOC/EXEC patients are impaired detecting selection restriction violations due to an executive resource deficit that limits the ability to integrate grammatical and semantic information into a coherent thematic matrix.

The sensitivity of SOC/EXEC patients to syntactic errors was dependent on the particular type of violation. They showed sensitivity to word class substitution errors in a sentence, suggesting that they may have access to information about a word’s major grammatical subcategory. In contrast, SOC/EXEC patients were not sensitive to morphosyntactic errors. Based on the available data regarding syntactic processing in SOC/EXEC patients, this is unlikely to be due to a broad-based grammatical deficit. Rather, morphosyntactic violations may require a particular kind of executive resource that is not necessary for phrase structure agreements. One possibility is the involvement of selective attention in processing morphosyntactic violations. SOC/EXEC patients are impaired on neuropsychological measures requiring selective attention (Boone et al., 1999; Rahman et al., 1999; Razani et al., 2001), and selective attention was implicated in grammatical processing using an online error-detection task with nonaphasic patients with Parkinson’s disease (Lee, Grossman, Morris, Stern, & Hurtig, 2003).

These observations are consistent with findings that left IFC, important for grammatical processing, is generally spared in SOC/EXEC patients, and would thus be available to subserve sentence processing. At the same time, cortical atrophy in SOC/EXEC patients is seen in medial and prefrontal portions of the frontal lobe associated with selective attention, perhaps accounting for some difficulty detecting an unstressed, perceptually subtle, morphosyntactic error (Grossman & Ash, 2004; Rosen et al., 2005, 2002; Williams et al., 2005).

5. Conclusion

Patients with FTD have difficulty processing sentences, with the basis for this difficulty depending on each patient's clinical presentation. PNFA patients are impaired at processing morpheme and word class violations but are relatively sensitive to a selection restriction type of error. SOC/EXEC patients, by comparison, are impaired in processing resource-dependent features of a sentence such as the detection of an unstressed morphosyntactic error and a selection restriction violation. These data provide further support for dissociable syntactic and thematic stages of sentence processing differentially impaired in these two groups of FTD patients.

Acknowledgments

This work was supported in part by National Institutes of Health (DC00237, AG17586, NS35867, and AG15116).

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