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Selectional restriction and semantic priming effects in normals and Broca's aphasics

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Abstract

Three experiments explored the extent to which patterns of abnormal comprehension in Broca's aphasia can be attributed to a disruption of information encoded in the selectional restrictions of verbs. An auditory lexical decision paradigm was used to examine sensitivity to selectional restriction relations between verbs and their noun arguments as well as to associative semantic relations. Experiment I explored these effects at the lexical level. Experiment II examined these effects in a simple syntactic context, and Experiment III compared these effects in grammatical and ungrammatical sentence contexts. Both normal and Broca's aphasic subjects showed sensitivity to selectional restrictions and semantic associates in both lexical and sentential contexts. However, although Broca's aphasics did show sensitivity to selectional restriction information associated with verbs, unlike normal subjects they failed to show a selection restriction effect in ungrammatical sentences, suggesting that access to selectional restriction information was less stable than access to semantic associative information. Implications of the results for normals and Broca's aphasics are discussed in relation to parallel and serial theories of sentence processing and to lexically based theories of aphasic language comprehension deficits.
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Keywords: Broca's aphasia; Selectional restrictions; Lexical processing; Sentence processing; Semantic priming

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1. Introduction

It has long been noted that Broca's aphasics demonstrate evidence of abnormal comprehension of certain sentence types (e.g. Caramazza, Berndt, Basili, & Koller, 1981). Broca's aphasics have been shown to have deficits in understanding passive sentences (Schwartz, Saffran, & Marin, 1980), subject- and object-gap sentences (Caramazza & Zurif, 1976), and other syntactically complex structures, particularly those with non-canonical word order (e.g. Schwartz et al., 1980).

Research on the basis of this comprehension problem has pointed variously to an inability to represent either all or a subclass of syntactic 'empty elements,' (Grodzinsky, 1986, 1995; Thompson, Tait, Ballard, & Fix, 1999), to an overall slowing of lexical access (Swinney, Zurif, Prather, & Love, 1996), and to a 'temporal mismatch in the availability of lexical and structural information' (Friederici & Kilborn, 1989, p. 263). Perhaps less explored has been the extent to which patterns of abnormal comprehension in Broca's aphasia can be attributed to a disruption of information available at the lexical level about the semantic relationships between words in a sentence, specifically, the information encoded in selectional restrictions of verbs. A number of recent studies have suggested that aphasic patients including Broca's aphasics have a lexical processing impairment (Prather, Zurif, Love, & Brownell, 1997; Utman, Blumstein, & Sullivan, 2001). Of interest are the types of information that are encoded at the lexical level. One proposal postulated by constraint based lexicalist theories of sentence processing is that a number of types of information are encoded in a lexical entry including thematic relations, argument structure, selectional restrictions, and frequency (Macdonald, Pearlmutter, & Seidenberg, 1994). According to this view, this information is immediately available and used to guide online sentence processing (Tanenhaus & Trueswell, 1995). Under the hypothesis that selectional restriction information is activated when a verb is activated, a deficit in lexical processing might lead to a deficit in accessing selectional restriction information.

Selectional restrictions are those semantic restrictions that any verb places on the arguments of that verb. For instance, in a sentence, the verb 'to mail' requires that the noun in subject position for that verb, that is, the 'mailer', must have certain semantic characteristics. The 'mailer' must be animate, human, and capable of volitional action. Likewise, the noun in object position must be something 'mail-able'—it must be an object that does not exceed the size and weight restrictions of the US Postal Service. The selectional restrictions of a verb are necessary for computing semantic relationships between elements in a sentence. The question addressed in this paper is whether Broca's aphasics have a disruption in their ability to access or use selectional restrictions. If they do, some portion of their sentence comprehension deficit may be attributable to this impairment.

A separate, but related question addressed in this study is the extent to which a coherent syntactic frame is necessary to compute semantic relationships between words in a sentence generally, and between verbs and their arguments specifically. Two studies with normal subjects have directly examined the effect of syntactic context on semantic integration of lexical items (O'Seaghdha, 1989; Schriefers, Friederici, & Rose, 1998). These studies investigated whether semantic priming between words embedded in syntactically coherent frames can be disrupted or eliminated if the syntactic frame itself is

ungrammatical. O'Seaghdha (1989) used simple noun phrases with semantically associated or semantically unassociated words embedded in them. The noun phrases were either grammatical, e.g. The *author* of this *book/floor,* or they were ungrammatical, e.g. *The *author* the and *book/floor*. Subjects were instructed to make a lexical decision on the final word of the visually presented string. A semantic priming effect was seen in the grammatical context, manifested by significantly faster reaction times to 'book' as compared to a neutral target 'floor.' This effect was eliminated, however, in the ungrammatical noun phrase. One should note that not only are the words 'author' and 'floor' semantically unrelated, but they also cannot fit coherently into the phrasal context given in the grammatical noun phrase.

Schriefers et al. (1998) attempted to replicate O'Seaghdha (1989) by exploring the same question but in a sentence context. Simple active declarative sentences were used in which the verb–object pairs were either semantically related or semantically unrelated, e.g. He *drinks/sees* the *wine*. Two types of ungrammaticality were created. In one condition, the words in the sentence were scrambled, e.g. *He the *drinks/sees wine*. In the other, a local syntactic violation was introduced in the form of a gender mismatch between the target object and its preceding determiner, e.g. *He *drinks/sees* $the_{(NEUT)}$ $wine_{(MASC)}$.

In contrast to O'Seaghdha's results, Schriefers et al. (1998) showed semantic priming in the scrambled context as well as in the grammatical sentence context. However, the semantic priming effect was eliminated in the gender mismatch context. Friederici and colleagues (1999) explain the persistence of the priming effect in scrambled contexts by positing that when there is no motivation for subjects to attempt to build a syntactic structure—that is, when the syntax is completely unparseable, syntactic processing never begins, and only intra-lexical semantic priming effects obtain. However, when a local violation of syntax occurs, the disruption of syntactic processing is sufficient to block the subsequent semantic integration of lexical items, resulting in the loss of semantic priming. If it is the case that lexical integration effects disappear when syntactic parsing fails in normal sentence comprehension, it may be possible to probe the intactness of Broca's aphasics' syntactic representations by investigating whether semantic priming is maintained or lost in grammatical and ungrammatical sentences.

While Broca's aphasics display patterns of disrupted syntactic comprehension, there is evidence that they are sensitive to some grammatical violations. Broca's aphasics exhibit an on-line sensitivity to grammatical errors, manifested by slower reaction times in a lexical decision task to the last word of ungrammatical sentences compared to grammatical sentences (Baum, 1988), and show sensitivity to local syntactic violations in a priming paradigm (Blumstein, Milberg, Dworetzky, Rosen, & Gershberg, 1991). In addition, agrammatic aphasics have been shown to be remarkably accurate in detecting grammatical errors even in when they occur in sentence constructions for which performance in comprehension tasks is poor (Grodzinsky, 2000; Linebarger, Schwartz, & Saffran, 1983).

Three experiments were designed to explore the processing of selectional restrictions in both normal subjects and Broca's aphasic patients. To this end, three types of verb–object pairs were created in which a verb prime was followed by a noun target. In the first condition, the noun target was semantically associated with the verb and also fit the selectional restrictions of the verb, e.g. *mail letter* (+*Sem,* +*SR*). In the second condition,

the verb and object were not semantically related, but the noun target fit the selectional restrictions of the verb, e.g. *find letter* (*−Sem, +SR*). In the third condition, the verb was both semantically unrelated to the object, and the object did not fit the selectional restrictions of the verb, e.g. *persuade letter* (*−Sem, −SR*). In Experiment 1 the three types of verb–object pairs were presented in the absence of syntax, that is, in a word–word priming experiment. The question explored was whether selectional restriction information of a verb is available at the lexical level even in the absence of a syntactic frame. It was expected that both normal subjects and Broca's aphasics would show semantic priming (i.e. reaction times to [+Sem, +SR] pairs would be faster than to [−Sem, +SR] and [−Sem, −SR] pairs). It was also expected that both groups of subjects would show sensitivity to selectional restrictions (i.e. reaction times to [+Sem, +SR] and [−Sem, +SR] pairs would be faster than to [−Sem, −SR] pairs) in a lexical context. Experiment II investigated whether a simple syntactic context would influence selectional restriction effects across the three verb–object conditions. Experiment III compared sensitivity to selectional restrictions in a grammatical and ungrammatical sentence context. Of particular interest was whether sensitivity to selectional restrictions would be diminished or lost in Broca's aphasics, particularly in an ungrammatical syntactic context.

2. Experiment I

2.1. Subjects

Thirteen normal subjects recruited from the Brown University community participated in this subject for monetary compensation. All subjects were naïve to the purpose of the experiment, and reported no known hearing loss. Eight Broca's aphasic subjects (five males and three females) ranging between 54 and 82 years of age at time of testing (mean age = 62.75) were also tested. Table 1 shows the clinical and neurological characteristics of each of the aphasic subjects.

Auditory stimuli were used in all studies. The experimental stimuli consisted of 36 target words that fit as objects in a simple subject–verb–object sentence frame. In the [+Sem, +SR] condition, each target was paired with a verb that was semantically related to the object noun, e.g. 'mail-letter'. For the [−Sem, + SR] condition, a verb that fit felicitously with the object but was not semantically related to it, was selected, e.g. 'find-letter'. For the [−Sem, −SR] condition, a semantically unrelated verb was selected that also did not fit felicitously with the target object, e.g. 'persuade-letter'.

The [+Sem, +SR] verb–object pairs were generated using a cloze procedure by presenting 10 subjects with a list of 50 common verbs and asking them to generate a potential object if the verb was in a simple sentence like 'She VERB-ed the —.' Thirty-six verbs from this set that were responded to with the same word six times out of 10 were chosen for inclusion in the study, along with the corresponding target word. To assure that the verb object pairs in the three experimental conditions met their selection criteria, five subjects were presented with a set of test sentences, and asked to judge whether the sentence was 'plausible' or 'implausible.' All [+Sem, + SR] and [−Sem, +SR] sentences which

Table 1
Aphasic data

Patient	Gender	Age at testing	Years post-onset	Auditory comprehension *Z*-score[a]	Etiology	Lesion
B1	F	56	11	+0.95	CVA	Large insular lesion extending to temporal lobe, sparing Wernicke's area and part of Broca's area
B2	M	71	25	+0.83	Aneurysm	Left frontal lesion involving the posterior half of Broca's area and most of the middle frontal gyrus extending into the white matter deep to these areas, and also including the head of the caudate and anterior limb of the internal capsule. It extends superiorly into the pre-motor, motor and sensory cortex areas and the white matter deep to these areas including the PVWM and undercutting fibers of the supplementary motor area.
B3	M	66	25	+0.87	CVA	Left hemisphere lesion in Broca's area and the white matter deep to it. Lower 2/3 of the pre-motor, motor, and sensory cortex; white matter and PVWM deep to those areas.
B4	M	82	22	+0.52	CVA	Left frontal lesion involving Broca's area with deep extension across to left frontal horn-lower motor cortex (face and lips). Includes part of the left temporal lobe.
B5	M	56	13	+0.95	CVA	Lesion involving left caudate and globus pallidus, anterior internal capsule to medial temporal cortex and insula, anterior PVWM.
B6	M	63	6	+0.77	CVA	Large lateral frontal lesion, a large lesion in the frontal operculum, and two small lesions, one in the motor cortex and the other in the caudate, putamen and ALIC.
B7	F	54	6	+0.81	CVA	Large left fronto-parietal lesion involving all of the inferior frontal gyrus including all of Broca's area and white matter deep to it; also involving insular cortex, lateral putamen, with extension across anterior temporal isthmus also lower pre-motor and motor cortex, supra-marginal gyrus and PVWM.
B9	F	55	3	+0.97	CVA	Lesion in anterior left MCA distribution centered on the Sylvian fissure and involving both grey and white matter; some extension into the left temporal and parietal lobes.

[a] *Z*-score for the four auditory comprehension subtests of the Boston Diagnostic Aphasia Exam (Goodglass & Kaplan, 1972)

Table 2
Sample stimuli for Experiment I

Condition	Prime verb	Word target	Non-word target
+Sem, +SR	Mail	Letter	Plew
−Sem, + SR	Find	Letter	Plew
−Sem, −SR	Persuade	Letter	Plew

received 'plausible' ratings from all subjects, and [−Sem, −SR] sentences which received 'implausible' ratings from all subjects were included in the stimulus set.

A distractor condition was also created. Thirty-six non-word targets that obeyed the phonotactics of English were generated. Each verb used in the experimental condition was presented once with its potential object, and once with a non-word target. (see Table 2 for sample stimuli and Appendix A for a complete list of prime—target pairs.) Verbs were frequency-matched across conditions (Kucera & Francis, 1967).

Stimuli were recorded by a male speaker using a digital recorder. These words were sampled into a PC computer for stimulus presentation. There was a 250 ms ISI and a 2000 ms ITI. Stimuli were organized into three blocks such that in each block subjects responded to each word target and each non-word target once, and no prime was repeated within a given block. Blocks were presented in random order, and items within each block were randomized.

Stimuli were presented binaurally. Subjects were told that they would be listening to pairs of words, the first of which would always be a real word of English. They were instructed to decide whether the second word in each pair was a real English word or a non-word, and to press the 'yes' button if it was a real word, and 'no' if it was a non-word. Subjects were told to perform as quickly and accurately as possible with their dominant hand. They were given five practice trials and asked if they had any questions about the procedure. They were offered short breaks after each of the three blocks in the experiment, which took about 20 min to complete. Responses were scored for both accuracy and reaction-time. Reaction-time latencies were measured from the onset of each target word until the subject responded by pressing a button on a button box.

The experiment was administered in the same way to aphasic participants, the only changes being a longer inter-trial interval (5 s rather than 2 s), and 10 practice trials rather than five.

2.2. Results

Reaction time data for the normal subjects and the Broca's aphasics were analyzed separately because of a lack of homogeneity of variance between the two groups. Latencies were analyzed for real word targets for the normal participants, removing all incorrect responses, all responses that were more than two standard deviations from the mean in each condition, and all responses that fell below 0 ms (indicating that the subjects responded before the onset of the lexical decision target stimulus). Fig. 1 shows the results. A one-way repeated measures ANOVA was performed and showed a significant main effect of Condition by both subjects ($F(2, 24) = 56.931$; $p < 0.001$) and by items

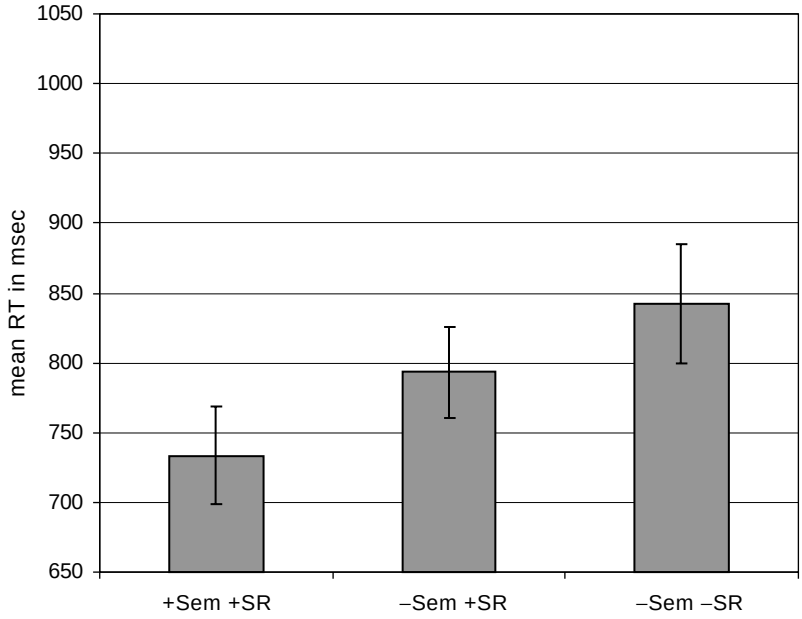

Fig. 1. Reaction-time results of normal subjects in Experiment I.

($F(2,105) = 12.237$; $p < 0.001$). Post hoc pair-wise comparisons yielded significant differences between all conditions. Thus, there was a significant effect of semantic priming, as well as an effect of selectional restrictions, with enhanced priming when the verb object was consistent with the selectional restrictions of the verb prime.

The same analysis was performed on the reaction time latencies for the aphasic participants. Results are shown in Fig. 2. As can be seen, despite their longer reaction-time latencies, a similar pattern of results emerged. A one-way repeated measures ANOVA confirmed these findings. There was a significant effect of Condition by subjects ($F(2,14) = 22.088$; $p < 0.001$) and by items ($F(2,105) = 5.305$; $p < 0.006$). Post-hoc pair-wise tests indicated that all conditions were significantly different from each other.

Table 3 shows the error rates for both normal and aphasic subjects. As expected, aphasic patients had higher error rates than normal subjects. However, the pattern of errors was similar for the two groups and also paralleled the reaction time data. There were more errors in the [−Sem, −SR] condition than in the other two conditions, and more errors in the [−Sem, +SR] condition than in the [+Sem, +SR] condition.

2.3. Discussion

The results of Experiment 1 show that both normal and Broca's aphasic subjects showed a semantic priming effect as well as sensitivity to the selectional restrictions of the verb. The semantic priming effect manifested itself in faster reaction times to

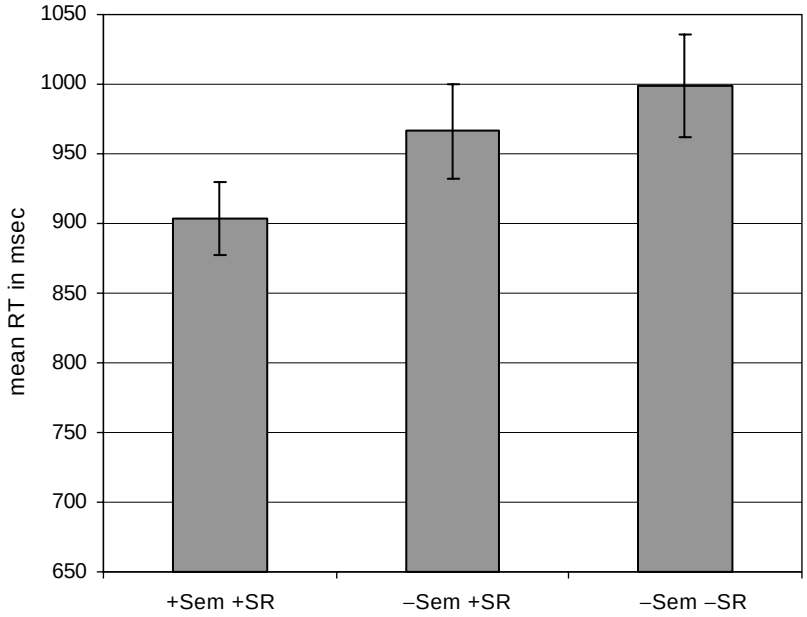

Fig. 2. Reaction-time results of Broca's aphasics in Experiment I.

the targets in the [+Sem, +SR] condition compared to the [−Sem, +SR] and [−Sem, −SR] conditions. In addition, sensitivity to the selectional restrictions of the verb was shown by significantly faster RT responses in the [−Sem, +SR] condition compared to the [−Sem, −SR] condition where the target noun was not consistent with the selectional restrictions of the preceding verb.

These findings suggest that selectional restriction information is available at the lexical level and does not emerge solely in a sentential context. These results are consistent with models of sentence processing that allow for the simultaneous and early use of lexical, semantic and pragmatic information in constraining syntactic processing (see Tanenhaus & Trueswell, 1995 for overview). Proponents of these 'constraint-based lexicalist' models have proposed that lexical representations contain richer information than previously supposed, including probabilistic information about the way words function grammatically and about syntactic relationships between words (Macdonald et al., 1994). Such lexically

Table 3
Mean percent error rates for Experiment I

Condition	Normals	Aphasics
[+Sem,+SR]	0.21	1.74
[−Sem, +SR]	2.14	6.94
[−Sem, −SR]	3.42	8.33
Non-word	2.64	6.71

specified syntactic information is used by subjects very quickly to constrain the interpretation of a sentence. Trueswell and Kim (1998) for example showed that subjects reading garden-path type sentences could be biased toward one subcategorization frame of a verb with two possible subcategorization frames if they were quickly presented ('fast primed') with a flashed verb which utilized only one of those frames. If lexically specified syntactic information is, in fact, richly represented and immediately used, the use of selectional restriction information available at the lexical level provides an explanation for the reaction time difference between the [−Sem, +SR] and [−Sem, −SR] conditions.

Broca's aphasics exhibited the same pattern as normal subjects, showing priming for semantically related pairs and faster responses when the object fit the selectional restrictions of the verb. As is typical of brain-damaged populations in general and aphasic populations specifically, reaction times were slowed compared to normals. It is apparent that much or all of the selectional restriction information available to normal subjects at a lexical level is also accessible by to the aphasic subjects, at least at this time course, and with these relatively low task demands.

The observation that selectional restriction information is available at the lexical level raises the question of whether the presence of an explicit syntactic frame will enhance sensitivity to selectional restriction information. When a verb and object are embedded in a syntactic frame, selectional information is obligatorily used and hence must be accessed. The goal of Experiment II is to investigate this question. Only normal subjects were tested in Experiment II since the goal was to determine whether both semantic priming and selectional restriction effects would emerge in a sentence context, and whether sensitivity to selectional restriction information would be greater in Experiment II than in Experiment I. Experiment III which does include Broca's aphasic patients replicates such effects with normals and also tests Broca's aphasics.

3. Experiment II

3.1. Subjects

Twelve young normal subjects were paid for their participation in the experiment. None of these subjects participated in Experiment I.

3.2. Stimuli and procedure

In an effort to be able to directly compare the results between Experiments I and II, simple present tense sentences of the form 'subject–verb–object' were constructed using the same verb–object pairs and experimental conditions used in Experiment I. Grammatical subjects were selected from a list of generic plural subjects (see Table 4 for sample stimuli, and Appendix A for a complete list of stimuli). The same male speaker as in Experiment I recorded three examples of each of the test sentences using normal declarative sentence prosody. From these recordings, one token of each subject, verb, and object was selected. The stimulus materials were then constructed by splicing the determiner + subject, verb and determiner + object segments together, with fifty

Table 4
Sample stimuli for Experiment II

Condition	Subject	Prime verb	Word target	Nonword target
+Sem, +SR	The men	Mail	The letter	The plew
−Sem, +SR	The men	Find	The letter	The plew
−Sem, −SR	The men	Persuade	The letter	The plew

milliseconds of silence between each spliced segment. One of the authors (EM) listened to all of the spliced sentences to assure that they had normal sentence intonation. In addition, pitch plots of the originally recorded and spliced sentences were compared for a subset of the sentences. No differences were found.

Stimuli were presented binaurally. Subjects were instructed that they would be hearing simple sentences, some of which would make sense, some of which would not. They were told to decide whether the last word of the sentence was a real English word or a non-word, and to press the appropriate button as quickly as possible without sacrificing accuracy. Seven practice trials were given to the subjects to accustom them to the task and to the sentence length. Trials were blocked as in Experiment I. Similar to Experiment I, reaction time latencies were measured from the onset of the lexical decision target stimulus until the subject made a button press response. There was no difference in the duration of the target words in Experiment II compared to those in Experiment I.

3.3. Results

Reaction time responses were analyzed as in Experiment I. The results are shown in Fig. 3. A one-way repeated measures ANOVA was significant by subjects ($F(2,22) = 26.984$; $p < 0.001$) and by items ($F(2,105) = 11.088$; $p < 0.001$). Post hoc pair-wise comparisons showed significant differences between all conditions.

These results were compared statistically to the results for the normal subjects from Experiment I. A two-way ANOVA, using Experiment as the between-subjects factor, and Condition as the within subjects factor showed a main effect of Condition ($F(2,46) = 76.251$; $p < 0.001$). There was no main effect of Experiment ($F(1,23) = 0.541$), nor was there an Experiment X Condition interaction ($F(2,46) = 0.547$). Post-hoc pairwise comparisons of the main effect for Condition showed significant differences between all experimental conditions ([+Sem, +SR], [−Sem, +SR] and [−Sem, −SR].)

Error rates are shown in Table 5. As in Experiment 1, error rates paralleled the reaction time results for the 'word' responses, with more errors made in the [−Sem, −SR] condition compared to both the [+Sem, +SR] and the [−Sem, +SR] conditions, and more errors in the [−Sem, +SR] condition than the [+Sem, +SR] condition.

3.4. Discussion

Results of Experiment II show that at least for grammatically simple sentences, overtly supplying a syntactic context does not significantly increase the magnitude of semantic priming or selectional restriction effects beyond what is provided by juxtaposing

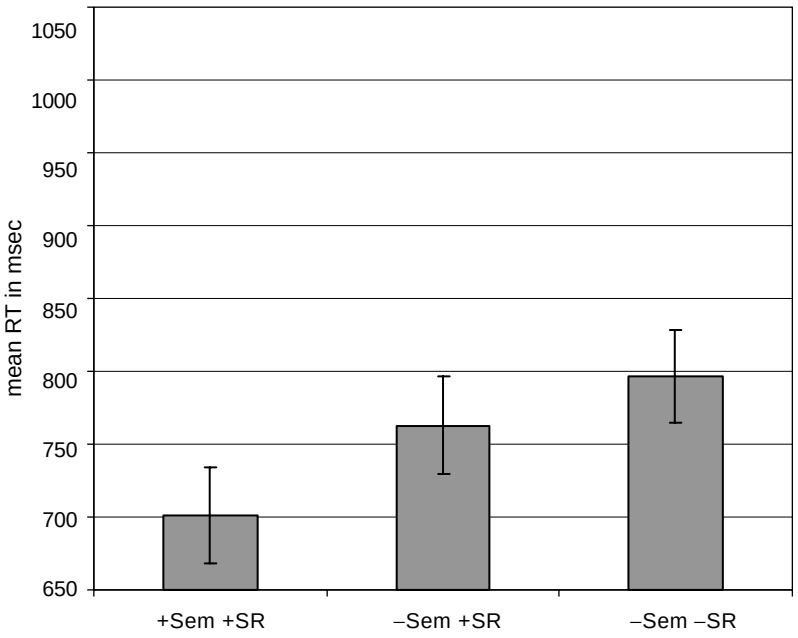

Fig. 3. Reaction-time results of normal subjects in Experiment II.

individual lexical items as in Experiment I. We cannot rule out the possibility that in Experiment I subjects were projecting a syntactic frame on to the verb–object pairs. However, if this were the case, we would still expect to see enhancement of selectional restriction effects when syntactic structure is present as in Experiment II. No such enhancement was observed in the statistical comparison of Experiments I and II. Having established in Experiment I that both semantic priming and selectional restriction effects obtain for these verb–object pairs in the absence of a syntactic context, and in Experiment II that similar effects emerge in the presence of a simple grammatical sentence structure, the question remains whether either or both effects would be eliminated by introducing a syntactic violation in a simple sentence frame. Indeed, O'Seaghdha (1989); Schriefers et al. (1998) propose that syntactic context is not necessary for semantic facilitation, but rather that the disruption of syntactic context will eliminate priming effects. Experiment III explores this issue in both normal subjects and Broca's aphasic patients.

Table 5
Mean percent error rates for Experiment II

Condition	Normals
+Sem, +SR	0.23
−Sem, +SR	2.55
−Sem, −SR	4.17
Non-word	0.77

4. Experiment III

4.1. Subjects

Twelve young normal subjects from the Brown University community participated for monetary compensation. The same eight Broca's aphasic subjects who participated in Experiment I were also tested. The order in which Experiments I and III was administered was counterbalanced across subjects with a two-week interval between these testing sessions. Because one of the aphasic patients was tested twice due to computer error in the first testing (B5 in Table 1), his data were not included in the final analysis.

4.2. Stimuli and procedure

The stimulus set consisted of the grammatical and distractor sentences from Experiment II and a set of sentences containing syntactic structure violations. The syntactic violation sentences were created from the grammatical sentences by replacing the article just before the target object with either a preposition or another non-determiner function word. As in Experiments I and II, there were three priming conditions. Table 6 shows examples of the test stimuli (see also Appendix B for a complete list of materials). The distance between the verb prime and the word final noun target was kept constant in all sentences at one word.

Sentences were recorded by the same male speaker as in the previous experiments. The grammatical subjects and prime verbs were the same as those used in Experiment II, but the target objects were new tokens of the same words. Recording and splicing procedures were identical to those in Experiment II. The duration of the new target tokens was not significantly different from the target words from Experiment II ($t = 0.3902$). The administration of Experiment III was the same as Experiment II. Aphasics received the same form of the test and the same instructions as normal subjects, except that there was a longer ITI for the aphasics (5 s compared to 2 s for the normals).

4.3. Results

As in Experiment 1, the data for the normal subjects and Broca's aphasic patients were analyzed separately due to a lack of homogeneity of variance between the two groups. Reaction time responses for normal subjects are shown in Fig. 4. A two-way ANOVA with Condition as one factor and Syntactic Violation as the other factor revealed a main effect

Table 6
Sample stimuli for Experiment III

Condition	Subject	Prime verb	Word target
			Grammatical/Syntactic violation
+Sem, +SR	The men	Mail	The/over letter
−Sem, + SR	The men	Find	The/over letter
−Sem, −SR	The men	Persuade	The/over letter

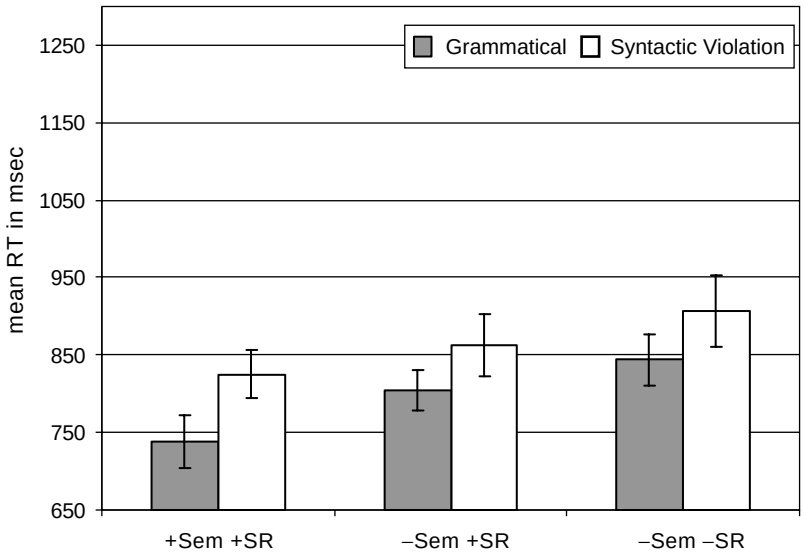

Fig. 4. Reaction-time results of normal subjects in Experiment III.

of Condition that was significant by subjects ($F(2,22)=38.786$; $p<0.001$) and by items ($F(2,210)=13.204$; $p<0.001$), Post-hoc pairwise comparisons revealed significant differences between all conditions ($p<0.01$). There was also a main effect of Syntactic Violation that was significant both by subjects ($F(1,11)=20.162$; $p<0.001$), and by items ($F(1,210)=38.204$; $p<0.001$), reflecting significantly slower reaction times in the sentences with syntactic violations compared to the grammatical sentences. There was no Condition by Syntactic Violation interaction ($F(2,22)=0.784$). These results indicate that although normal subjects were significantly slowed in all conditions by the syntactic violation in the sentences, the magnitude of both semantic priming and sensitivity to selectional restrictions was maintained regardless of syntactic context.

Results from the seven aphasic subjects are shown in Fig. 5. A two-way ANOVA revealed a significant main effect of Condition by subjects ($F(2,12)=11.651$; $p<0.002$) and by items ($F(2,209)=7.325$; $p<0.001$). Post-hoc pairwise tests showed a significant difference between [+Sem, +SR] and the other two conditions. However, the difference between the [−Sem, +SR] and [−Sem, −SR] conditions did not reach significance. There was also a main effect of Syntactic Violation which was significant by subjects ($F(1,6)=18.756$; $p<0.005$) and by items ($F(1,209)=46.563$; $p<0.001$), with slower responses for sentences containing a local syntactic violation. The Syntactic Violation by Condition interaction approached significance by subjects ($F(2,12)=3.78$; $p<0.053$). Post-hoc tests of simple effects revealed that the interaction was due to a significant difference in the magnitude of the selectional restriction effect for grammatical and ungrammatical sentences. That is, grammatical sentences showed an effect of selectional restrictions, whereas this difference was lost in the ungrammatical sentences.

As in the previous two experiments, error rates paralleled the reaction time means for ‘yes’ responses for both normals and Broca’s aphasics (see Table 7).

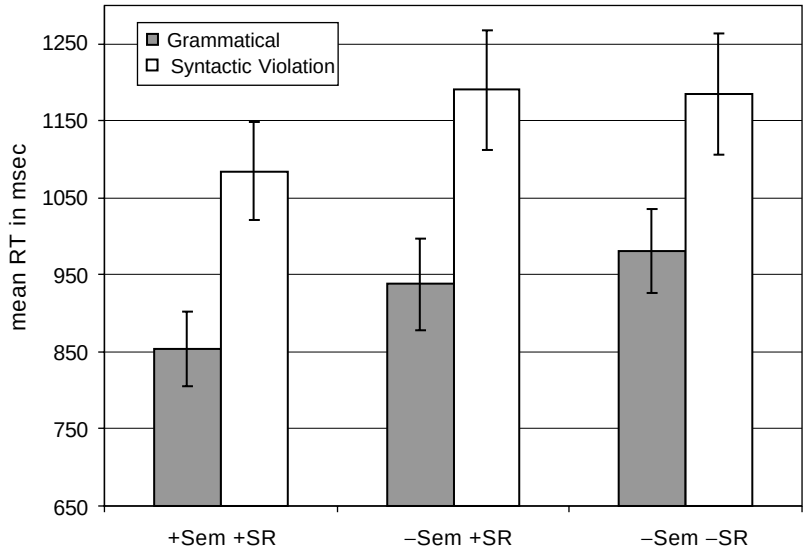

Fig. 5. Reaction-time results of Broca's aphasics in Experiment III.

4.4. Discussion

The results of Experiment III show that for both normal and aphasic patients, the presence of a syntactic violation slows overall processing. However, both groups show semantic priming irrespective of the grammaticality of the sentence. With respect to sensitivity to selectional restrictions, normal subjects show selectional restrictions effects in both grammatical and ungrammatical sentences. In contrast, aphasic patients demonstrate sensitivity to selectional restrictions only in grammatical sentences.

Table 7
Percent error rates for Experiment III

	Syntactically OK	Syntactic violation
Normals		
+Sem +SR	0.46	2.31
−Sem +SR	3.78	6.48
−Sem −SR	3.70	12.50
Non-word	0.77	2.16
Aphasics		
+Sem +SR	0.69	9.03
−Sem +SR	2.78	17.36
−Sem −SR	2.78	26.39
Non-word	4.40	4.40

5. General discussion

The results of Experiments I–III provide evidence that on the presentation of a verb, its semantic associates are partially activated as well as its possible verb arguments. Consistent with this view are the findings of a semantic priming effect and a selectional restriction effect in normal subjects both at the lexical level and in a sentential context. While it may not be surprising to find a semantic priming effect at both lexical and syntactic levels of processing, it is perhaps unexpected that selectional restriction effects would emerge on the lexical level, in the absence of a syntactic context, and also in a simple sentence frame containing a syntactic violation. In fact, the emergence of a selectional restriction effect for ungrammatical sentences is inconsistent with the results of O'Seaghdha (1989) and Schriefers et al. (1998). Both of these studies showed that semantic priming was eliminated when a local violation of syntax was introduced. In the current study, while reaction times in all conditions were significantly slowed in the ungrammatical condition, the magnitude of the semantic priming effect was maintained regardless of syntactic context for normal subjects, as was the selectional restriction effect. Even when the syntax of these simple sentences was unparseable, subjects still relied on the potential relationship between verb and object to perform this task.

The consistency of both the semantic priming and selectional restriction effects across all experiments suggests that normal subjects, at least for a simple syntactic structure, and at this time course, utilize all information available at the lexical level when constructing a syntactic frame and a meaning representation. These results are consistent with a number of studies that have shown on-line, rapid use of information about a verb's argument structure (Altmann, 1999; Altmann & Kamide, 1999; Boland, Tanenhaus, Garnsey, & Carlson, 1995; Macdonald et al., 1994; McRae, Ferretti, & Amyote, 1997; Trueswell & Kim, 1998).

Taken together, the results of Experiments I–III support models of language processing that allow for the simultaneous and early use of lexical, semantic and pragmatic information in sentence processing (Tanenhaus & Trueswell, 1995). They challenge those models of language processing in which syntactic processing occurs first on the basis of word category information, followed by integration of lexical items into that syntactic frame, and computation of semantic relationships based on positions in that frame. Such models would not predict selectional restriction effects at the lexical level nor would they predict semantic priming or selectional restriction effects with a disruption of syntactic parsing introduced by syntactic violations (Friederici, Pfeifer, & Hahne, 1993; Friederici et al., 1999).

The patterns of results for the Broca's aphasics were striking in their similarity to the normal subjects. While aphasic responses were slower overall than the normals' responses, the general pattern of results deviated from the normal subjects in only one respect: the failure to show sensitivity to selectional restrictions in the syntactic violation condition in Experiment III. Thus, as predicted, Broca's aphasics showed stable semantic priming at the lexical level, and they showed semantic priming in grammatical sentences, consistent with the observation that Broca's aphasics rely on semantic information in assigning thematic roles, even when syntactic information conflicts with that assignment (Saffran, Schwartz, & Linebarger, 1998). They also showed sensitivity to syntactic

violations, exhibited in slower lexical decision times in the ungrammatical sentences (Baum, 1988).

The appearance of both semantic and selectional restriction effects in Experiment I and in grammatical sentences in Experiment III provides strong evidence for the intactness of semantic associations and selectional restrictions in Broca's aphasics. However, the fact that semantic priming effects were maintained and selectional restriction effects were lost in the ungrammatical sentences suggests that selectional restriction information may be more weakly activated than semantic associative relationships and hence are more vulnerable to disruption.

The question is why. As discussed above, constraint based lexicalist theories of language processing hypothesize that the nature of the lexical representation of words is richer than in more traditional modular theories of language. Thus, not only is semantic associative information part of the lexical representation, but so is selectional restriction information. In a series of papers, Milberg, Blumstein and colleagues have proposed that Broca's aphasics have a lexical processing deficit characterized by a reduction in the activation level of lexical candidates (Milberg, Blumstein, Katz, Gershberg, & Brown, 1995). If it is assumed that both lexical-semantic information and selectional restriction information is a part of the lexical representation of words, as proposed by constraint-based theories, then both lexical-semantic information and selectional restriction information are potentially vulnerable in Broca's aphasics. That selectional information is more vulnerable is due to the fact that in contrast to the lexical semantic network of a word which is rich in associations and semantic relationships, selectional restriction information is limited to only those semantic attributes that a particular verb places on its arguments. Because the 'network' of selectional restrictions is sparser than that of semantic associations, it is more vulnerable under conditions of a reduction in lexical activation. Thus, this proposal makes the claim that the difference between the encoding of semantic associative information and selectional restriction information is quantitative (i.e. the richness of the network with which it is associated) and not qualitative (i.e. the nature of the encoding of this type of information). Similar arguments have been made with respect to open and closed class word categories in relation to syntactic impairments in Broca's aphasics (Blumstein & Milberg, 2000). Taken together, these arguments suggest that deficits which on the surface may appear to be syntactic in nature may be due to lexical processing impairments.

It is important to note that one probable consequence of a decrease in activation of the lexicon is that any individual lexical item will take longer to reach threshold (Utman et al., 2001). In particular, delay in access of a verb will result in a delay in the activation of information associated with it, such as subcategorization frames, thematic roles, and selectional restriction information. This delay will lead to an incompatibility in mapping lexical information to its syntactic frame, resulting in what would appear to be a syntactic deficit especially in syntactically complex sentences. This view is compatible with those theories that have proposed that syntactic processing is essentially intact but is slowed in Broca's aphasics (Burkhardt, Pinango, & Wong, 2003; Haarmann & Kolk, 1991). For example, Broca's aphasics show reactivation of the filler at the gap site, although the reactivation appears to be delayed (Blumstein et al., 1998; Burkhardt et al., 2003; Zurif et al., 1993). The results of Experiment III suggest that disparities exist in the access to

specific types of lexical information (i.e. selectional restrictions vs. semantic associative information) as well as the overall speed or strength of activation for aphasics relative to normals.

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Appendix A. Prime—Target Pairs for Experiments I, II and III

Verb prime type			Target object
(+Sem +SR)	(−Sem +SR)	(−Sem −SR)	Word
Rent	Clean	Throw	Apartment
Bounce	Move	Learn	Ball
Ring	Toss	Satisfy	Bell
Pay	Obtain	Eat	Bill
Read	Forget	Promise	Book
Blow	Catch	Pay	Bubble
Light	Like	Open	Candle
Drive	Remember	Read	Car
Wear	Check	Attend	Clothes
Hunt	Touch	Build	Deer
Wash	Bring	Kill	Dishes
Dress	Drop	Light	Doll
Open	Kick	Steer	Door
Start	Cover	Dress	Engine
Sweep	Choose	Receive	Floor
Smell	Place	Deceive	Flower
Serve	Buy	Attempt	Food
Call	Consult	Sweep	Friend
Play	Change	Meet	Game
Break	Admire	Plant	Glass
Chew	Discover	Visit	Gum
Brush	Smooth	Drive	Hair
Build	Lose	Cook	House
Paint	Hide	Brush	Picture
Turn	Shake	Boil	Knob
Mail	Find	Persuade	Letter
Cook	Complete	Paint	Meal
Lose	Hold	Alarm	Money
Tear	Distribute	Wear	Paper
Pilot	Inspect	Ring	Plane
Write	Trade	Serve	Play

(*continued on next page*)

Verb prime type			Target object
(+Sem +SR)	(−Sem +SR)	(−Sem −SR)	Word
Plant	Sell	Suffer	Seed
Sew	Approve	Control	Shirt
Boil	Prefer	Pack	Stew
Pack	Grab	Call	Suitcase
Drink	Select	Ride	Wine

Appendix B. Stimuli for Experiments II and III

Subject	(+Sem +SR)	(−Sem +SR)	(−Sem −SR)	Target
The men	Rent	Clean	Throw	An/over apartment
The women	Bounce	Move	Learn	A/into ball
They	Ring	Toss	Satisfy	A/up bell
The girls	Pay	Obtain	Eat	The/or bill
The girls	Read	Forget	Promise	The/below book
The girls	Blow	Catch	Pay	A/down bubble
They	Light	Like	Open	A/around candle
They	Drive	Remember	Read	A/through car
The boys	Wear	Check	Attend	The/above clothes
They	Hunt	Touch	Build	The/at deer
They	Wash	Bring	Kill	The/near dishes
The girls	Dress	Drop	Light	A/by doll
The boys	Open	Kick	Steer	A/before door
The women	Start	Cover	Dress	The/for engine
The women	Sweep	Choose	Receive	The/after floor
The women	Smell	Place	Deceive	The/on flower
The boys	Serve	Buy	Attempt	The/of food
They	Call	Consult	Sweep	A/in friend
The kids	Play	Change	Meet	A/to game
The girls	Break	Admire	Plant	A/toward glass
The men	Chew	Discover	Visit	The/inside gum
The men	Brush	Smooth	Drive	Their/outside hair
The men	Build	Lose	Cook	A/between house
They	Paint	Hide	Brush	A/out picture
The kids	Turn	Shake	Boil	The/beside knob
They	Mail	Find	Persuade	The/with letter
The kids	Cook	Complete	Paint	A/without meal
They	Lose	Hold	Alarm	The/onto money
They	Tear	Distribute	Wear	The/under paper
They	Pilot	Inspect	Ring	The/and plane
They	Write	Trade	Serve	A /across play
They	Plant	Sell	Suffer	The/though seed
They	Sew	Approve	Control	The/since shirt
They	Boil	Prefer	Pack	The/but stew
The men	Pack	Grab	Call	A/when suitcase
They	Drink	Select	Ride	The/where wine

References

Altmann, G. T. M. (1999). Thematic role assignment in context. *Journal of Memory and Language*, *41*, 124–145.

Altmann, G. T. M., & Kamide, Y. (1999). Incremental interpretation at verbs: restricting the domain of subsequent reference. *Cognition*, *73*, 247–264.

Baum, S. R. (1988). Syntactic processing in agrammatism—Evidence from lexical decision and grammaticality judgment tasks. *Aphasiology*, *2*, 117–135.

Blumstein, S. E., Byma, G., Kurowski, K., Hourihan, J., Brown, T., & Hutchinson, A. (1998). On-line processing of filler-gap constructions in aphasia. *Brain and Language*, *61*, 149–168.

Blumstein, S. E., & Milberg, W. P. (2000). Language deficits in Broca's and Wernicke's aphasia: A singular impairment. In Y. Grodzinsky, & L. P. Shapiro, *Language and the brain: Representation and processing. Foundations of neuropsychology series* (pp. 167–183). San Diego, CA: Academic Press, 167–183.

Blumstein, S. E., Milberg, W. P., Dworetzky, B., Rosen, A., & Gershberg, F. (1991). Syntactic priming effects in aphasia—an investigation of local syntactic dependencies. *Brain and Language*, *40*, 393–421.

Boland, J. E., Tanenhaus, M. K., Garnsey, S. M., & Carlson, G. N. (1995). Verb argument structure in parsing and interpretation: Evidence from wh-questions. *Journal of Memory and Language*, *34*, 774–806.

Burkhardt, P., Pinango, M. M., & Wong, K. (2003). The role of the anterior left hemisphere in real-time sentence comprehension: Evidence from split intransitivity. *Brain and Language*, *86*, 9–22.

Caramazza, A., Berndt, R. S., Basili, A. G., & Koller, J. J. (1981). Syntactic processing deficits in aphasia. *Cortex*, *17*, 333–348.

Caramazza, A., & Zurif, E. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language*, *3*, 572–582.

Friederici, A., & Kilborn, K. (1989). Temporal constraints on language processing: Syntactic priming in Broca's aphasia. *Journal of Cognitive Neuroscience*, *1*, 262–272.

Friederici, A., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing—Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research*, *1*, 183–192.

Friederici, A., Steinhauer, K., & Frisch, S. (1999). Lexical integration: Sequential effects of syntactic and semantic information. *Memory and Cognition*, *27*, 438–453.

Goodglass, H., & Kaplan, E. (1972). *The assessment of aphasia and related disorders*. Philadelphia: Lea and Febiger.

Grodzinsky, Y. (1986). Language deficits and theory of syntax. *Brain and Language*, *27*, 135–159.

Grodzinsky, Y. (1995). A restrictive theory of agrammatic comprehension. *Brain and Language*, *50*, 27–51.

Grodzinsky, Y. (2000). The neurology of syntax: Language use without Broca's area. *Behavioral and Brain Sciences*, *23*, 1–21.

Haarmann, H. J., & Kolk, H. H. J. (1991). Syntactic priming in Broca's aphasics: Evidence for slow syntax. *Aphasiology*, *5*, 247–263.

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day american english*. Providence: Brown University Press.

Linebarger, M. C., Schwartz, M. F., & Saffran, E. M. (1983). Sensitivity to grammatical structure in so-called agrammatic aphasics. *Cognition*, *13*, 361–392.

Macdonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review*, *101*, 676–703.

McRae, K., Ferretti, T. R., & Amyote, L. (1997). Thematic roles as verb-specific concepts. *Language and cognitive processes*, *12*, 137–176.

Milberg, W., Blumstein, S. E., Katz, D., Gershberg, F., & Brown, T. (1995). Semantic facilitation in aphasia-effects of time and expectancy. *Journal of Cognitive Neuroscience*, *7*, 33–50.

O'Seaghdha, P. G. (1989). The dependence of lexical relatedness effects on syntactic connectedness. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 73–87.

Prather, P. A., Zurif, E., Love, T., & Brownell, H. (1997). Speed of lexical activation in nonfluent Broca's aphasia and fluent Wernicke's aphasia. *Brain and Language*, *59*, 391–411.

Saffran, E. M., Schwartz, M. F., & Linebarger, M. C. (1998). Semantic influences on thematic role assignment: Evidence from normals and aphasics. *Brain and Language*, *62*, 255–297.

Schriefers, H., Friederici, A. D., & Rose, U. (1998). Context effects in visual word recognition: Lexical relatedness and syntactic context. *Memory and Cognition*, *26*, 1292–1303.

Schwartz, M. F., Saffran, E. M., & Marin, O. S. (1980). The word order problem in agrammatism: I. Comprehension. *Brain and Language*, *10*, 249–262.

Swinney, D., Zurif, E., Prather, P., & Love, T. (1996). Neurological distribution of processing resources underlying language comprehension. *Journal of Cognitive Neuroscience*, *8*, 174–184.

Tanenhaus, M. K., & Trueswell, J. C. (1995). Sentence comprehension. In J. Miller, & P. Eimas, *Speech, language, and communication*. *Handbook of perception and cognition* (pp. 217–262). San Diego: Academic Press, 217–262.

Thompson, C. K., Tait, M. E., Ballard, K. J., & Fix, S. C. (1999). Agrammatic aphasic subjects' comprehension of subject and object extracted Wh questions. *Brain and Language*, *67*, 169–187.

Trueswell, J. C., & Kim, A. E. (1998). How to prune a garden path by nipping it in the bud: Fast priming of verb argument structure. *Journal of Memory and Language*, *39*, 102–123.

Utman, J. A., Blumstein, S. E., & Sullivan, K. (2001). Mapping from sound to meaning: Reduced lexical activation in Broca's aphasics. *Brain and Language*, *79*, 444–472.

Zurif, E., Swinney, D., Prather, P., Solomon, J., et al. (1993). An on-line analysis of syntactic processing in Broca's and Wernicke's aphasia. *Brain and Language*, *45*, 448–464.