

Building up Linguistic Context in Schizophrenia: Evidence From Self-Paced Reading

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An impairment in the build-up and use of context has been proposed as a core feature of schizophrenia. The current study tested the hypothesis that schizophrenia patients show impairments in building up context within sentences because of abnormalities in combining semantic with syntactic information. Schizophrenia patients and healthy controls read and made acceptability judgments about sentences containing verbs that were semantically associated with individual preceding words but that violated either the meaning (animacy/semantic constraints) or the syntactic structure (morphosyntactic constraints) of their preceding contexts. To override these semantic associations and determine that such sentences are unacceptable, participants must integrate semantic with syntactic information. These sentences were compared with congruous and pragmatically/semantically violated sentences that imposed fewer semantic–syntactic integration demands. At sentence-final words and decisions, patients showed smaller reaction time differences than controls to animacy/semantically violated or morphosyntactically violated sentences relative to pragmatically/semantically violated or nonviolated sentences. The relative insensitivity to these violations in patients with schizophrenia may arise from impairments in combining semantic and syntactic information to build up sentence context.

Keywords: schizophrenia, language, semantics, syntax, context

As we make sense of the world around us, we must constantly integrate individual pieces of information to build up context and form a coherent gestalt. This must occur fast, effortlessly, and without our being aware of these pieces of information. An impairment in building up and using context has been proposed as a core cognitive deficit of schizophrenia that is evident across a number of cognitive domains (Cohen & Servan-Schreiber, 1992). We have proposed that an impairment in the build-up of linguistic context may, at its most extreme, lead to some of the most devastating verbal symptoms of schizophrenia, including positive thought disorder or language disorganization (Kuperberg, McGuire, & David, 1998, 2000).

Evidence that healthy individuals build up and use context during language processing comes from the use of a contextual

violation paradigm in which participants are asked to read, listen to, recall or judge sentences with words that are either congruous or that violate their preceding context. Healthy individuals easily distinguish between normal and linguistically violated sentences. During online processing, reaction times (RTs) are longer (Fischler & Bloom, 1979; Marslen-Wilson, Brown, & Tyler, 1988; Schwanenflugel & Shoben, 1985; Stanovich & West, 1983; Tyler, 1992), and the electrophysiological response (the N400) is larger (Kutas & Hillyard, 1980, 1984) to words that violate their preceding contexts than to words that are congruous with these contexts, suggesting that violations of context can disrupt processing. On the other hand, when participants are asked explicitly to decide whether a sentence is acceptable, judgment times can be faster to some types of violated sentences than to congruous sentences (Kuperberg, Holcomb, et al., 2003; McElree & Griffith, 1995), suggesting that once such violations have been detected, processing is attenuated.

Patients with schizophrenia are less sensitive to such contextual violations in sentences than healthy controls: They are impaired in their ability to recall (Truscott, 1970) or make plausibility judgments (Anand, Wales, Jackson, & Copolov, 1994; Kuperberg et al., 1998; Tamlyn et al., 1992) about violated versus nonviolated sentences. In addition, in an online word-monitoring paradigm, we demonstrated that, in comparison with controls, patients took longer to detect target words that were congruous relative to words that violated their preceding context (Kuperberg et al., 1998, 2000). Moreover, several other studies have reported reduced modulation of the electrophysiological (N400) response to incongruous (relative to congruous) words in patients relative to controls (Adams et al., 1993; Mitchell et al., 1991; Ohta, Uchiyama, Matsushima, & Toru, 1999; but see Andrews et al., 1993; Nestor et al., 1997; Niznikiewicz et al., 1997).

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Little, however, is known about the mechanisms by which this insensitivity to sentence context arises in schizophrenia. The build-up of sentence context requires us not only to process the meaning of individual words but to establish a syntactic structure and to combine the meanings of words with this structure (Caplan, 1992). Early studies suggest that, like controls, patients are able to use syntactic constraints during online processing (Carpenter, 1976; Grove & Andreasen, 1985; Rochester, Harris, & Seeman, 1973). However, there is growing evidence that patients' insensitivity to context in sentences is maximal when the demands to integrate semantic and syntactic information are greatest, suggesting that the primary deficit may be at the level of combining semantic with syntactic information. First, in the word-monitoring study outlined above, patients were least sensitive to context in sentences where the relationships between verbs and their arguments violated both semantic and syntactic or thematic constraints rather than pure pragmatic/semantic constraints (Kuperberg et al., 1998). Second, in electrophysiological studies, patients are least sensitive to context when violations are introduced on sentence-final words, where wrap-up demands to integrate semantic and syntactic information are greatest (Adams et al., 1993; Mitchell et al., 1991; Ohta et al., 1999).

The current study further examined the theory that patients, in comparison with healthy controls, are impaired in combining semantic and syntactic information to build up context and make sense of sentences. Participants read and made acceptability judgments about sentences with congruous lexico-semantic relationships between nouns and verbs, but in which overall meaning (animacy/semantic thematic constraints) or syntactic structure (morphosyntactic constraints) was violated. In animacy/semantically violated sentences, violations were introduced between an inanimate subject noun and a verb that required an animate subject noun for the sentence to make sense (e.g., "For breakfast the eggs would only eat. . ."; Table 1, Sentence Type 3). In morphosyntac-

tically violated sentences, there were agreement mismatches between the subject noun and the critical verb (e.g., "For breakfast the boys would only eats. . ."; Table 1, Sentence Type 4). To determine that both these types of sentences are unacceptable, the reader must override the potentially congruous semantic relationships ("breakfast" – "boys" – "eats"; "breakfast" – "eggs" – "eats") and combine the meaning of each of these words with the syntactic or thematic structure of the sentence (Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, in press; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). We contrasted such sentences with nonviolated sentences (e.g., "For breakfast the boys would only eat. . ."; Table 1, Sentence 1) and with pragmatically/semantically violated sentences in which violations were introduced at the level of relating the verb–noun relationship to an incongruous preceding clause (e.g., "For breakfast the boys would only bury. . ."; Table 1, Sentence Type 2). In these sentences, there was no conflict between lexico-semantic associations and syntactic or thematic structure.

This study followed up a previous experiment in which we measured patients' and controls' electrophysiological responses on critical verbs in these same types of sentences (Kuperberg, Sitnikova, Goff, & Holcomb, 2006). Patients showed a normal electrophysiological response (a normal N400 waveform) to verbs in the pragmatically/semantically violated sentences. However, in comparison with healthy controls, they produced a smaller electrophysiological response (a smaller P600 waveform) to verbs in both the animacy/semantically violated and the morphosyntactically violated sentences. Although this electrophysiological study documented online neurophysiological abnormalities at the point of midsentence critical verbs in schizophrenia, it did not address the question of how these violations affect processing difficulty at the end of the sentence or at the point of decision. Behaviorally, do patients show a relative insensitivity to context at the same point as

Table 1
Description and Examples of Sentence Types

Sentence type	Explanation	Examples ^a
1. No violation	Baseline condition against which the other conditions are evaluated.	"For breakfast the boys would only <u>eat</u> toast and jam." "Before the important final exams many students began to <u>study</u> ."
2. Pragmatic/semantic violation ^b	The critical verb is replaced by another verb taken from another sentence scenario. This makes the sentence unpredictable with respect to real-world knowledge.	"For breakfast the boys would only <u>bury</u> toast and jam." "Before the important final exams many students began to <u>bully</u> ."
3. Animacy/semantic violation ^c	The animate noun that is assigned the role of Agent by the critical verb is replaced by an inanimate noun. This makes the sentence implausible.	"For breakfast the eggs would only <u>eat</u> toast and jam." "Before the important final exams many textbooks began to <u>study</u> ."
4. Morphosyntactic violation	The verb is changed either to violate subject–verb agreement or by using a finite verb in place of an infinitival verb.	"For breakfast the boys would only <u>eats</u> toast and jam." "Before the important final exams many students began to <u>studies</u> ."

^a Two examples of scenarios are given for each sentence type. The first scenario has a critical verb (underlined) that occurs before the end of the sentence, and the second has a critical verb (underlined) that is a sentence-final word. ^b We follow Marslen-Wilson, Brown, and Tyler (1988) in the use of the term *pragmatic* for these types of violations. We do not imply that real-world knowledge is not used in processing the animacy/semantically violated sentences. However, in the pragmatically/semantically violated sentences, the anomaly could not be determined simply by considering the relationship between the subject noun and the verb; it could only be determined by considering the entire context of the sentence with respect to one's real-world pragmatic knowledge. We also use the term *semantic* to emphasize that these are violations of meaning. ^c Our use of the term *animacy violation* conveys the fact that in all of these sentences, an inanimate subject noun was used together with verbs that assign the role of Agent (normally animate in nature) to their preceding subject noun in simple English sentences (Agent-Theme or Experiencer-Theme verbs). Again, we use the word *semantic* to emphasize that these are violations of meaning.

when they show an abnormal electrophysiological response—when critical verbs appear midsentence? Or does a behavioral insensitivity to context manifest primarily at the final word of the sentence and at the point of making an explicit acceptability judgment? This question is important because as we build up sentence meaning word by word, the demands to integrate semantic and syntactic information become progressively greater and are maximal at clause boundaries and at the ends of sentences when participants generally wrap up what they have read to make sense of the sentence as a whole.

To address these questions, we presented the four types of sentences described in Table 1, word by word, to patients with schizophrenia and demographically matched healthy controls. Participants silently read each word in each sentence as it appeared on the computer screen and simply pushed a response key to trigger the presentation of subsequent words. In half the sentences, the critical verb was the sentence-final word. In the other half, the critical verb appeared before the end of the sentence (see Table 1 for examples). This enabled us to measure reading times at midsentence critical verbs, sentence-final critical verbs, and sentence-final noncritical words. We also asked participants to decide, at the end of each sentence, whether or not the sentence was acceptable and measured decision times to make these judgments. We hypothesized that patients with schizophrenia would show maximal impairment in processing animacy/semantically and morphosyntactically violated sentences where, to make correct acceptability judgments, the demands to integrate semantic and syntactic information are greatest. In addition, we hypothesized that these abnormalities would be most marked on sentence-final words and at the point of making decisions about sentence acceptability where, once again, semantic–syntactic integration demands are maximal.

Method

Recruitment and Assessment of Participants

Thirty-two patients with schizophrenia (12 from the Maudsley Hospital, London, and 20 from the Erich Lindemann Mental Health Center, Boston) were originally recruited. Thirty-two healthy controls (9 from London and 23 from Boston) were recruited by advertisement. Selection criteria required all participants (patients and controls) to be native speakers of English and to have normal or corrected-to-normal vision. Exclusion criteria for all participants included neurological disease or damage, head trauma with documented cognitive sequelae or loss of consciousness for more than 10 minutes, medical disorders that can impair neurocognitive function, substance abuse within 3 months, or any history of substance dependence. Written informed consent was obtained from all participants according to the established guidelines of the Human Subjects Research Committees for the Maudsley Hospital and Massachusetts General Hospital.

Diagnoses of patients were made by staff psychiatrists and were confirmed by a psychiatrist (the first author) using a structured clinical interview (Spitzer, Williams, Gibbon, & First, 1992) and examination of the case notes. All patients met criteria for schizophrenia listed in the *Diagnostic and Statistical Manual of Mental Disorders* (fourth edition [DSM-IV]; American Psychiatric Association, 1994). All patients were receiving stable doses of antipsychotic medication. Healthy volunteers were not taking any medication and were screened (Spitzer et al., 1992) to exclude the presence of psychiatric disorders.

All participants were administered the National Adult Reading Test (NART; Nelson, 1982) or the North American Adult Reading Test (NAART; Blair & Spreen, 1989) as an estimate of premorbid verbal IQ.

Patients' symptomatology was rated with the Positive and Negative Syndrome Scale (PANSS; Kay, Fiszbein, & Opler, 1987). A summary of positive and negative symptoms for each participant was generated by summing positive and negative items of the PANSS respectively. In addition, an overall global measure of psychopathology was generated by summing the positive, negative, and general items of the PANSS.

Thought disorder in the patient group was assessed with the scale for the assessment of Thought Language and Communication (TLC; Andreasen, 1979a, 1979b, 1986). On the basis of previous factor analyses (Liddle, 1987; Peralta, Cuesta, & de Leon, 1992) and following the approach we adopted in our previous behavioral studies (Kuperberg et al., 1998, 2000), a positive thought disorder, or "verbal disorganization" score, was calculated by summing the following eight subscores of the TLC: loss of goal, tangentiality, derailment, illogicality, incoherence, distractibility, neologisms, and word approximations. Additional subscores on the TLC (poverty of speech, perseveration, blocking and poverty of speech content) were also summed to give a measure of negative thought disorder for each participant.

As described in the Results section, we report the data of a subset of 20 patients who performed relatively accurately on the task and 20 controls who were selected to match these patients demographically.

Self-Paced Reading Task

Stimulus materials. A total of 240 Agent-Theme or Experiencer-Theme verbs were selected, and nonviolated active sentences containing animate subject noun phrases (NPs) were constructed for each of them (see Kuperberg, Sitnikova, et al., 2003, for more details). In half the sentences, the critical verbs were sentence-final words, and in the other half, the critical verb was followed by two to six words.

The animacy/semantically violated sentences were constructed by replacing the animate NP with an inanimate NP that was semantically associated with the critical verb and/or other preceding content words. Syntactically violated sentences were constructed by introducing a morphosyntactic violation, either by violating subject–verb agreement or by using a finite verb in place of an infinitival verb (see Kuperberg, Caplan et al., 2006). The pragmatically/semantically violated sentences were constructed by replacing the critical verbs with a verb that was chosen pseudorandomly from sentences of another list (see below).

So that no participant would encounter the same word more than once (leading to repetition priming effects) but also so that, across all participants, all critical verbs would be seen in all four conditions, the sentences were divided into four lists that were counterbalanced among participants. This excluded the possibility that any differences found among conditions were due to differences in participants' recognition of different words. Thus, in each list, there were 240 test sentences (60 of each of the four experimental conditions: normal, pragmatically/semantically violated, animacy/semantically violated, and morphosyntactically violated sentences).

Procedure. Participants were randomly assigned to one of the four counterbalancing lists. Trials were presented in pseudorandom order on a Macintosh laptop computer, interfaced with a three-button response box, using Psyscope software. Participants rested their hand near the response box such that their finger was just above the middle button. Sentences were presented word by word (rapid serial visual presentation), with each word displayed in black font centered on a white background. Participants were instructed to read each word silently and to push the middle button to move on to the next word. The final word of each sentence ended with a period and, on pressing the button to this sentence-final word, participants heard a beep, indicating that the sentence had ended, and then saw a response prompt with the words "good" and "bad" on the left and right of the screen. Participants' task was to decide whether or not each sentence was acceptable by pressing the corresponding left or right button on the response box. They were told that sentences may be unacceptable in different ways and that if sentences seemed at all odd, unlikely, or ungrammatical, they should indicate that it was unacceptable. Button responses were counterbalanced across participants. Participants were told that they could make a decision

at any point in the sentence but were instructed to only press the decision buttons once they heard the beep indicating that they had reached the end of the sentence. The 240 trials were presented in four blocks of 60 sentences. At the end of each block, participants were encouraged to take a break. They were given examples to practice at the beginning of the experiment.

Each time participants pressed a button, reading times or decision times were recorded. Each event (word or response prompt) in each sentence was coded such that these reading/decision times at each point within each sentence could be measured and subsequently analyzed. In addition, participants' acceptability judgments were recorded. In the Results section, we report reading times to critical words, sentence-final words, and decision times. We also report acceptability judgment accuracies.

Statistical Analysis

Accuracy. Accuracy was computed as the percentage of correct responses. An incorrect response was a judgment of "unacceptable" for the normal sentences (a false negative) and of "acceptable" for the anomalous sentences (a false positive). The percentages of false negatives and positives were calculated for each participant. Trials on which participants responded before the decision prompt (anticipations) were included. On trials where participants responded twice at the decision prompt (double responses), the first response was considered. Although each type of violated sentence was equally likely to be encountered, taken as a whole, 75% of the sentences included showed some type of violation. This might have introduced a response bias as participants made their acceptability judgments.¹ Therefore, in addition to calculating false positive and false negatives, *A'* scores—a nonparametric signal detection measure (Grier, 1971)—were also calculated. Participants who responded with less than 75% accuracy to two or more of the different sentence types and/or who had *A'* scores of less than 0.7 were excluded. For included participants, the effects of group (control, schizophrenic) and sentence type (normal, pragmatically/semantically violated, animacy/semantically violated, syntactically violated) on decision accuracy were examined with repeated measures analyses of variance (ANOVAs), with subjects as a random effect.

Reading and decision times. Reading and decision times are reported only for correctly answered trials, eliminating any possibility that RT differences in patients relative to controls were driven entirely by the trials on which patients made incorrect judgments. However, because patients made significantly more errors than controls, the exclusion of incorrectly answered trials might have potentially biased the between-groups comparison by selectively reducing power to detect any reading or decision time differences in the patient group. We therefore also conducted analyses in which all trials were included. The pattern of results was qualitatively similar to that in which only correctly answered trials were included.

In examining RTs to decisions, all anticipations and double-response trials were removed from the analysis. The distribution of RTs in both groups was skewed to the right, particularly in patients. In order to reduce this skew and to stabilize the variance between patient and control groups, we logarithmically transformed raw RT data before conducting ANOVAs. The results of these ANOVAs are reported in the Results section. However, all analyses were also conducted on raw data, with qualitatively similar results.

The effects of group (control, schizophrenia) and sentence type (normal, pragmatically/semantically violated, animacy/semantically violated, or syntactically violated) on RTs to midsentence critical verbs, sentence-final critical verbs, sentence-final noncritical words, and acceptability decisions were examined with repeated measures ANOVAs using subjects as a random effect (subjects analyses). The dependent variable was RT, collapsed across individual items for a given sentence type. Sentence type was a within-subject variable and group was a between-subjects variable. In addition, we conducted item analyses in which the dependent variable was the average RT for each of the 240 individual items (collapsed over individual subjects): Both group and sentence type were between-subjects variables. Subjects and items analyses that revealed significant interactions

Table 2

Demographic and Psychopathological Data of Healthy Controls and Patients With Schizophrenia

Variable Parameter	Participant group	
	Controls	Patients
Gender (M/F)	18/2	17/3
Age in years	41 (8)	42 (9)
Education in years	12.4 (2)	11 (2)
Hollingshead index	4.3 (5)	3.5 (1)
Race (AC/AA/C)	1/2/18	1/4/16
Premorbid IQ	118.7 (8.0)	117.8 (8.5)
CPZ equivalent		410 (317)
Duration of illness (years)		20 (8)
PANSS positive	16.3 (7.9)	
PANSS negative	18.3 (4.4)	
PANSS total		66.4 (19.0)
TLC positive	7.2 (5.2)	
TLC negative	2.6 (1.4)	

Note. Means are shown with standard deviations in parentheses. Patients and controls matched closely in gender, and there was no significant difference between the groups in age ($p = .57$). Patients had 1 year less education (significant at $p < .05$) than controls but no significant difference in premorbid IQ ($p = .75$) as assessed by the National Adult Reading Test (Nelson, 1982) or the North American Adult Reading Test (Blair & Spreen, 1989). The patient and control groups showed no significant difference ($p = .62$) on parental socioeconomic status as determined by Hollingshead index scores (Hollingshead, 1965). All participants were right-handed, as assessed with the modified Edinburgh Handedness Inventory (Oldfield, 1971; White & Ashton, 1976). M = Male; F = Female; AC = Afro-Caribbean; AA = African-American; C = Caucasian; CPZ = chlorpromazine; PANSS = Positive and Negative Syndrome Scale (Kay et al., 1987); TLC = Thought Language and Communication (Andreasen, 1979a, 1979b, 1986).

were followed up with simple effects analyses and, when these analyses were significant, with four paired *t* tests, comparing each of the anomalous sentence types with the nonviolated sentences. Therefore, if a subjects analysis but not an items analysis revealed a significant group by sentence type interaction, then this was followed up with a subjects analysis but not an items analysis, and vice versa. Group by sentence type interactions that reached significance on both subjects and items analyses were followed up with both subjects and items analyses. In overall ANOVAs, alpha was set at .05. In follow-up *t* tests, we used a Bonferroni correction for the four contrasts examined (each type of violation vs. nonviolated sentences) and set alpha at .0125.

We also calculated an RT measure of the sensitivity of each patient to each type of violated sentence relative to nonviolated sentences at each of the same points within the sentences as described above: RTs at midsentence critical verbs, sentence-final critical verbs, and sentence-final non-

¹ We had used these same sentence stimuli in two previous studies with healthy individuals. In the first study, which included normal, pragmatically/semantically violated sentences and animacy/semantically violated sentences, we used filler stimuli such that 50% of stimuli were violated and 50% of stimuli were nonviolated (Kuperberg, Holcomb, et al., 2003). In the second study, which included all four sentence types and used the same design as the current study, we did not use fillers so as to reduce the overall length of the experiment (Kuperberg, Caplan, et al., 2006). (Length of experiment was a particularly important consideration in the current patient study.) The same patterns of accuracy were observed across the sentence types in both of these previous studies, suggesting that, at least in healthy individuals, the unequal distribution of normal and anomalous sentences did not change the pattern of acceptability judgments to these sentences.

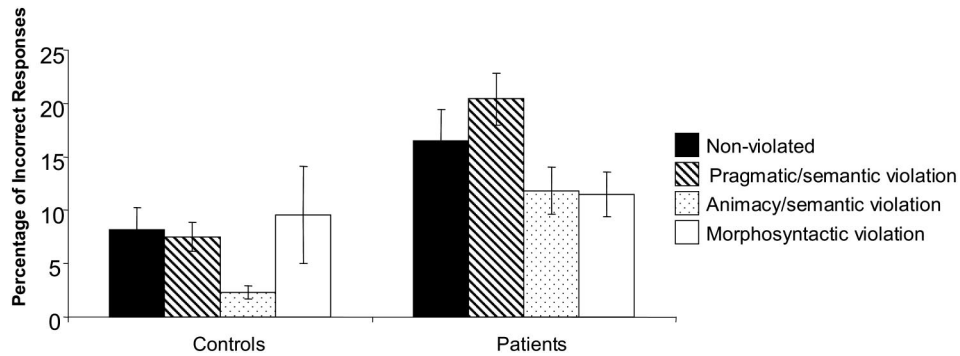


Figure 1. Percentages of errors to different types of sentences. Means are shown with error bars depicting standard errors.

critical words, as well as at decisions in the normal sentences, were subtracted from the corresponding RTs in the pragmatically/semantically, animacy/semantically, and morphosyntactically violated sentences. We then carried out correlations between these RT difference scores and various psychopathological measures within the patient group. Alpha was set at $p < .05$ for our a priori hypothesis that positive thought disorder would inversely correlate with RT difference scores. Because all other correlational analyses were exploratory, alpha was set at $p < .007$ (Bonferroni corrected for the seven psychopathological variables examined).

Results

Exclusion of Participants

Consistent with our previous findings (Kuperberg et al., 1998, 2000), there was marked variability and heterogeneity across individual schizophrenic patients in their response accuracies to each type of sentence. There are many reasons why patients might arrive at different conclusions from controls about whether or not a sentence is acceptable, including an inability to engage in the task at all. Although subsequent debriefing of most patients suggested that they had understood the task and were attending to the sentences (they were able to remember and talk about many of the sentences), we could not be sure of this. Therefore, we excluded 12 patients according to the criteria discussed in the Method section and report analyses for the subset of 20 patients who performed the task relatively accurately. Demographic and psychopathological details of these included patients are reported in Table 2 (right). The excluded patients had more severe psychopathology than the

included patients, with an average total PANSS score of 88.4, which was significantly higher than that of the included patients, $t(26) = 2.9, p < .007$. This difference was particularly evident in the negative PANSS score, which was 28.4 in the excluded patients—significantly higher than that in the included patients, $t(26) = 2.5, p < .02$. Excluded patients were also receiving higher doses of antipsychotic medication (chlorpromazine equivalents: 739) than the included patients $t(26) = 2.7, p < .013$. The excluded patients, however, did not differ significantly from the included patients in the severity of their positive symptoms, positive or negative thought disorder, duration of illness, or the demographic parameters listed in Table 2 (all t s < 1.78 ; all p s $> .08$). Twenty control participants were then selected to match the 20 included patients on various demographic characteristics (reported in Table 2). When we included all participants in analyses, the findings were qualitatively similar to those reported below.

Acceptability Judgments

As expected, patients performed significantly less accurately than controls, $F(1, 38) = 22.2, p < .001, \eta_p^2 = .372$. The percentage of false negatives (responding that a normal sentence was not acceptable) was 8.1% in controls and 16.5% in patients. The percentage of false positives (responding that a linguistically violated sentence was acceptable) was 6.5% in controls and 14.5% in patients. A' scores for all included subjects were more than 0.8. The percentages of errors to each sentence type in patients and controls are shown in Figure 1. There was no significant main

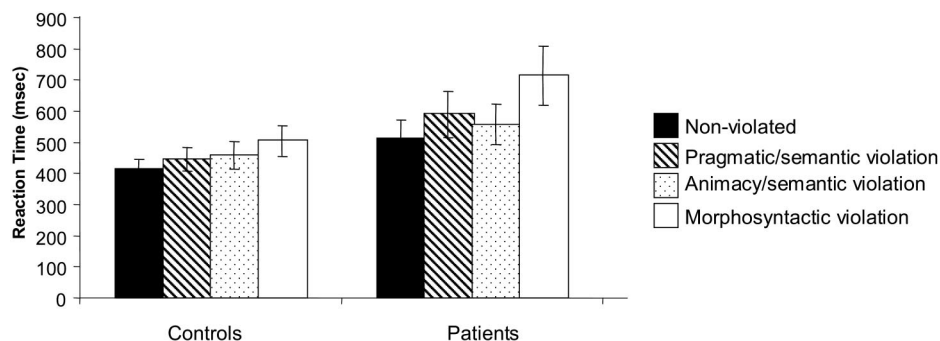


Figure 2. RTs at midsentence critical verbs within each type of sentence. Means are shown with error bars depicting standard errors.

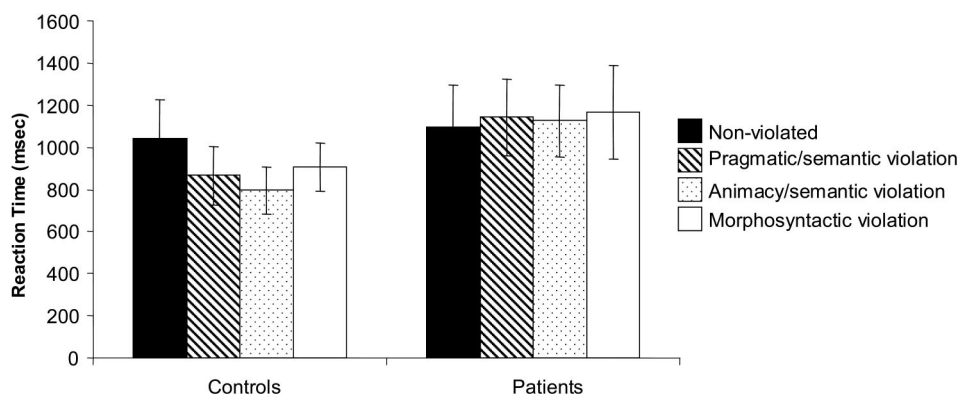


Figure 3. RTs at sentence-final critical verbs within each type of sentence. Means are shown with error bars depicting standard errors.

effect of sentence type, $F(3, 114) = 2.6, p = .07$, and patients and controls showed the same pattern of responses across the four sentence types—there was no group by sentence type interaction, $F(3, 114) = 1.61, p = .20$.

Reading Times to Midsentence Critical Verbs

Reading times to midsentence critical verbs are displayed in Figure 2. Reading times were generally slower in patients than controls, with differences reaching significance on the items analysis, $F_2(1, 479) = 89.62, p < .0001, \eta_p^2 = .158$, but not on the subjects analysis, $F_1(1, 38) = 1.38, p = .25$. Patients and controls showed no significant differences in the pattern of their RTs across the four sentence types, as reflected by the absence of a significant sentence type by group interaction, $F_1(3, 114) = 0.69, p < .54$; $F_2(3, 479) = 1.85, p = .138$. Across both groups, there was a significant main effect of sentence type, $F_1(3, 114) = 12.00, p < .001, \eta_p^2 = .240$; $F_2(3, 479) = 7.66, p < .001, \eta_p^2 = .046$, as a result of increases in reading times across the four sentence types, with shortest reading times to the normal nonviolated verbs, longer reading times to the pragmatically/semantically and the animacy/semantically violated verbs, and the longest reading times to the morphosyntactically violated verbs. This pattern was reflected by a significant linear contrast across the four sentence types in the subjects analysis, $F(1, 38) = 27.28, p < .001, \eta_p^2 = .418$.

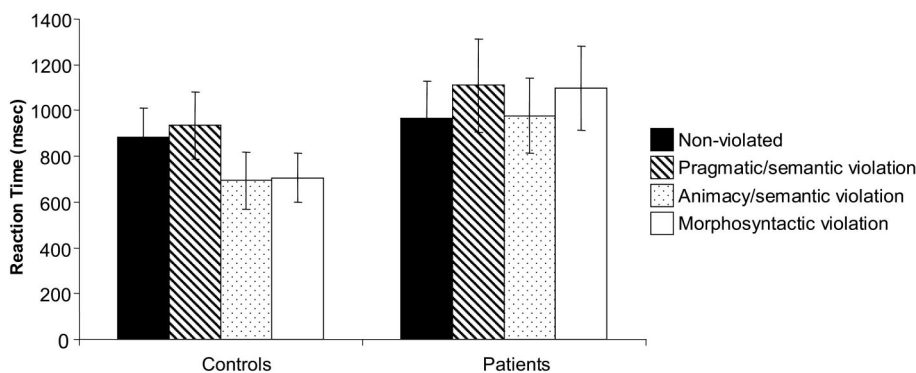


Figure 4. RTs at sentence-final noncritical words within each type of sentence. Means are shown with error bars depicting standard errors.

Reading Times to Sentence-Final Critical Verbs

Figure 3 shows reading times to sentence-final critical verbs. These reading times were generally slower in patients than controls, with differences again reaching significance on the items analysis, $F_2(1, 472) = 48.30, p < .0001, \eta_p^2 = .093$, but not on the subjects analysis, $F_1(1, 38) = 0.16, p = .70$.

There was a significant sentence type by group interaction on the items analysis, $F_2(3, 472) = 4.85, p < .01, \eta_p^2 = .03$, although not on the subjects analysis, $F_1(3, 114) = 0.47, p = .16$. Follow-up items analyses showed that this interaction arose because of a significant main effect of sentence type in the control group, $F_2(3, 472) = 5.90, p < .01, \eta_p^2 = .036$, but not in the patient group, $F_2(3, 472) = 1.89, p = .13$. The differences between sentence types in the control group on the items analysis arose because of significant differences between reading times to nonviolated critical verbs and animacy/semantic violations, $t_2(236) = 3.88, p < .001$, and morphosyntactic violations, $t_2(236) = 3.07, p < .01$.

Reading Times to Sentence-Final Noncritical Words

Figure 4 shows reading times to sentence-final noncritical words. Just as for sentence-final critical words, reading times to sentence-final noncritical words were slower in patients than controls, with differences reaching significance on the items analysis,

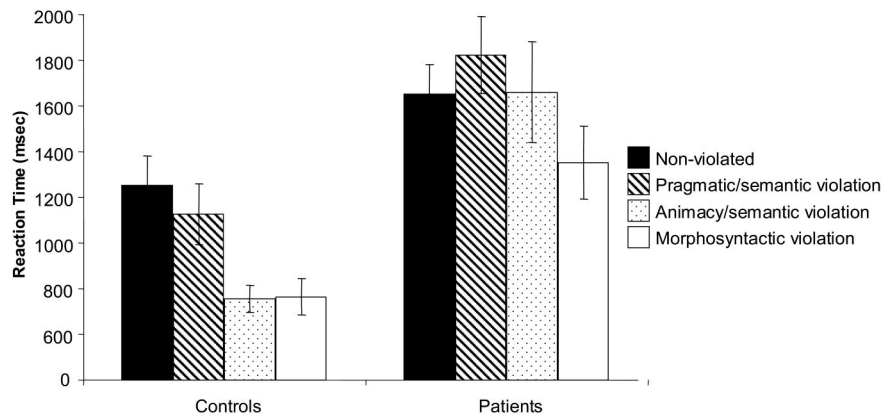


Figure 5. RTs at decision for each type of sentence. Means are shown with error bars depicting standard errors.

$F_2(1, 481) = 58.10, p < .001, \eta_p^2 = .108$, but not on the subjects analysis, $F_1(1, 38) = 0.80, p = .37$.

Patients and controls showed different patterns of reading times across the four sentence types, manifest by significant sentence type by group interactions, $F_1(3, 114) = 4.5, p < .01, \eta_p^2 = .106$; $F_2(3, 481) = 7.2, p < .001, \eta_p^2 = .043$. Follow-up analyses revealed a significant main effect of sentence type in the control group, $F_1(3, 57) = 7.67, p = .001, \eta_p^2 = .288$; $F_2(3, 479) = 22.05, p < .001, \eta_p^2 = .121$, as a result of shorter reading times to noncritical final words in the animacy/semantically violated and morphosyntactically violated sentences relative to the nonviolated sentences. All these differences reached our threshold for significance on follow-up *t* tests of both subjects and items analyses except the difference between morphosyntactic and nonviolated words on the subjects analysis follow-up: for animacy/semantically violated vs. nonviolated words, $t_1(19) = 3.36, p = .003, t_2(241) = 4.09, p < .0001$; for morphosyntactically violated versus nonviolated words, $t_1(19) = 2.39, p = .027, t_2(241) = 4.94, p < .0001$. Patients failed to show significant differences in reading times across the four sentence types in the subjects analysis, $F_1(3, 57) = 1.40, p = .26$, but did show differences in the items analysis, $F_2(3, 479) = 2.89, p = .035, \eta_p^2 = .018$. Follow-up *t* tests to this items analysis, however, failed to show significant differences between sentence types (all *t*s < 2.5, all *p*s > .05).

Decision Times

Decision times (see Figure 5) were slower in patients than controls. These differences were significant in both subjects and items analyses, $F_1(1, 38) = 16.50, p < .001, \eta_p^2 = .303$; $F_2(1, 951) = 337.70, p < .001, \eta_p^2 = .262$.

Once again, there were significant sentence type by group interactions, $F_1(3, 114) = 4.55, p < .01, \eta_p^2 = .107$; $F_2(3, 951) = 9.69, p < .001, \eta_p^2 = .03$. Follow-up analyses revealed a main effect of sentence type in the control group, $F_1(3, 57) = 16.36, p < .0001, \eta_p^2 = .463$; $F_2(3, 956) = 72.47, p < .0001, \eta_p^2 = .185$, that arose because of significantly shorter times to make decisions to both the animacy and morphosyntactically violated sentences than to the nonviolated and pragmatically/semantically violated sentences: animacy/semantically violated vs. nonviolated sentences, $t_1(19) = 7.54, p < .0001, t_2(476) = 10.53, p < .0001$; animacy/semantically violated versus pragmatically/

semantically violated sentences, $t_1(19) = 4.99, p < .0001, t_2(478) = 7.02, p < .0001$; morphosyntactically violated versus nonviolated sentences, $t_1(19) = 4.53, p < .0001, t_2(473) = 12.91, p < .0001$; and morphosyntactically violated versus pragmatically/semantically violated sentences, $t_1(19) = 3.29, p = .004, t_2(475) = 9.36, p < .0001$. Patients also showed a main effect of sentence type, $F_1(3, 57) = 7.84, p = .001, \eta_p^2 = .292$; $F_2(3, 951) = 19.71, p < .0001, \eta_p^2 = .059$. This arose because of significantly shorter decision times to the morphosyntactically violated sentences than to the nonviolated sentences, $t_1(19) = 3.93, p < .001, t_2(473) = 5.61, p < .0001$. The difference in response times to animacy/semantically violated relative to nonviolated sentences on follow-up analyses, however, failed to reach our threshold for significance, $t_1(19) = 0.93, p = .37$; $t_2(476) = 2.06, p = .04$.

Summary

As summarize in Table 3, group by sentence type interactions were observed in the items analyses at sentence-final critical words and in both subjects and items analyses at sentence-final noncritical words and at decision. These interactions arose because, relative to healthy controls, patients were less sensitive (showed smaller differences in RT) at these points in animacy and morphosyntactic violated sentences than to nonviolated sentences.

Effects of Clinical Variables

Within the patient group, correlations between (a) RT differences between each of the three violated sentence types and the normal sentences at midsentence critical verbs, sentence-final critical verbs, sentence-final noncritical words, and decisions, and (b) total negative PANSS score, total positive PANSS score, and total PANSS score, were not significant (all Spearman *r*s < .43, all *p*s > .20, except for the correlation between total negative PANSS score and RT decision times to pragmatically/semantically violated, relative to nonviolated, sentences, $r = .55, p = .02$). Correlations between these RT difference scores and positive or negative thought disorder scores derived from the TLC were also not significant (all Spearman *r*s < .42, all *p*s > .07, except for the correlation between negative thought disorder and midsentence

Table 3
Summary of Results

Analysis	Mid-sentence critical verbs		Sentence-final critical verbs		Sentence-final noncritical words		Decisions	
	Subjects	Items	Subjects	Items	Subjects	Items	Subjects	Items
Group by sentence type interaction	<i>ns</i>	<i>ns</i>	<i>ns</i>	**	**	***	**	***
Within-group ANOVA								
Controls	—	—	—	**	***	***	****	****
Patients	—	—	—	<i>ns</i>	<i>ns</i>	*	**	****
<i>t</i> test: Pragmatic vs. nonviolated								
Controls	—	—	—	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
Patients	—	—	—	—	—	<i>ns</i>	<i>ns</i>	<i>ns</i>
<i>t</i> test: Animacy vs. nonviolated								
Controls	—	—	—	***	**	****	****	****
Patients	—	—	—	—	—	<i>ns</i>	<i>ns</i>	<i>ns</i>
<i>t</i> test: Syntactic vs. nonviolated								
Controls	—	—	—	**	<i>ns</i>	****	****	****
Patients	—	—	—	—	—	<i>ns</i>	***	****

Note. When group by sentence type interactions or within-group analyses of variance (ANOVAs) failed to reach significance, subsequent tests were not carried out, as indicated by dashes. For overall and simple effects ANOVAs, alpha was set at $p < .05$. For follow-up *t* tests, alpha was set at $p < .01$ (Bonferroni corrected for the four comparisons carried out in each group).

* $p < .05$. ** $p < .01$. *** $p < .001$. **** $p < .0001$.

RTs to morphosyntactically violated relative to nonviolated verbs, $r = -.54$, $p = .026$). There were no significant correlations between any of these RT differences and PANSS measures of hallucinations (all Spearman r s $< .46$, all p s $> .07$, except for the correlation with midsentence RTs to animacy/semantically violated relative to nonviolated verbs, $r = .63$, $p = .01$), or delusions (all Spearman r s $< .36$, all p s $> .16$, except for the correlation with midsentence RTs to animacy/semantically violated relative to nonviolated verbs, $r = .50$, $p = .043$). Finally, there were no significant correlations between any of these RT differences and medication dosage (all Spearman r s $< .45$, all p s $> .06$, except for the correlation with sentence-final critical words in animacy/semantically violated relative to nonviolated sentences, $r = .488$, $p = .036$). None of these correlations met our a priori threshold of significance ($p < .007$).

Discussion

Patients with schizophrenia and healthy controls showed different patterns of RTs as they processed and judged the acceptability of animacy/semantically and morphosyntactically violated sentences. These differences were observed both on sentence-final noncritical verbs (and less robustly on sentence-final critical verbs) and at the point where participants made explicit decisions about whether sentences were acceptable. These RT abnormalities were not driven by the trials that were answered inaccurately, as we only considered RTs to correctly answered trials.² They cannot be accounted for by demographic differences between the patient and control groups, and they held up to a logarithmic transformation that stabilized the variance between the two groups. We first discuss the patterns of RT findings in patients and controls at different points in the sentences in more detail and then consider their functional significance.

At midsentence positions, healthy controls showed longer reading times to verbs that violated their preceding context than to nonviolated verbs. This is consistent with previous studies in healthy individuals that used a word-monitoring paradigm and that demonstrated longer RTs to detect midsentence target words that violated their preceding context, relative to those that were congruous with their preceding context (Marslen-Wilson et al., 1988; Tyler, 1992). However, unlike in previous studies that compared patients with schizophrenia and healthy controls (Kuperberg et al., 1998, 2000), the current study failed to reveal a sentence type by group interaction at the midsentence position. In these previous word-monitoring studies, participants were not asked to process the sentences for meaning: Their only task was to monitor for target words in sentences that were presented auditorily. It may be that, in the current study, the requirement for participants to self-pace their way through the visually presented sentences and, at the end, to make decisions about their acceptability, reduced our sensitivity to detect reading time differences between violated and nonviolated verbs before the end of sentences. This is a known problem with self-paced reading tasks in which the processing of each word can spill over into the time in which subsequent words are presented, and participants can get into a routine of tapping the buttons at regular intervals. Reduced RT differences across sen-

² It is possible, however, that the increased error rate in patients reflected, in part, the same underlying abnormality as their abnormal pattern of RTs on the correctly answered trials: On trials where patients performed accurately, they still found it more difficult than healthy controls and therefore took longer than healthy controls to make acceptability judgments about violated (relative to nonviolated) sentences; on the error trials, patients' sensitivity to linguistic violations may have broken down altogether.

tence types within each group might have, in turn, reduced our power to detect differences between patient and control groups at the midsentence position.³

As summarized above, the most marked differences between patients and controls arose after midsentence critical words—at the ends of sentences (most robustly at noncritical sentence-final words⁴) and at the point of making explicit decisions about the acceptability of these sentences. Of note, in healthy controls, the pattern of RTs across sentence types at these sentence-final positions differed from the pattern of RTs across sentence types at midsentence critical verbs: Before the ends of sentences, violations disrupted processing, leading to longer RTs to violated than to nonviolated verbs, whereas end-of-sentence and decision RTs to both the animacy and the morphosyntactic violated sentences were shorter than in the nonviolated sentences. Shorter decision RTs to violated sentences relative to nonviolated sentences are consistent with previous findings in healthy individuals and have been interpreted as reflecting a reduced processing for meaning once syntactic or thematic structural violations have been detected (Kuperberg, Holcomb, et al., 2003). Patients, on the other hand, did not show attenuated RTs to animacy or morphosyntactically violated sentences (relative to nonviolated sentences) to the same degree as controls, even though they came to the correct conclusion that these sentences were unacceptable. Indeed, patients showed no significant differences in RT between the nonviolated sentences and the animacy/semantically violated sentences at any point in the sentence and only showed a difference between RTs to morphosyntactically violated and nonviolated words at the point of decision.

The demonstration that patients with schizophrenia show an abnormal pattern of RTs across normal, animacy, and morphosyntactically violated sentences on sentence-final words (particularly sentence-final noncritical words), and at the point of making acceptability judgments about these sentences, confirms our predictions. We interpret these abnormal RT patterns in schizophrenia as reflecting an impairment in combining the semantic meaning of individual words with syntactic structure to build up context in sentences. In the animacy and morphosyntactically violated sentences, the relatively close semantic relationships between individual words (e.g., “breakfast,” “boys,” “eat”/“eats”) contradicted the actual thematic or syntactic structure of these sentences. The need to overcome these potential semantic relationships to determine that such sentences are unacceptable imposes a high demand on the processing system to integrate semantic with syntactic information. These semantic–syntactic integration demands are even greater at sentence-final words (where the overall meaning of sentences is evaluated at wrap-up) and at the point of making explicit decisions about sentence acceptability.

We suggest that the primary abnormality in patients lies in their ability to combine semantic with syntactic information effectively, rather than in their ability to compute any syntactic structure. Evidence for this is that patients did show some sensitivity to the morphosyntactic violations at the point of decision (even though these RT differences were smaller than in controls). This is consistent with our electrophysiological findings with the same stimuli, which also revealed some sensitivity to morphosyntactic violations (Kuperberg, Sitnikova, et al., 2006). It also accords with the findings of classic behavioral studies demonstrating that patients can build up basic syntactic structures (Carpenter, 1976; Grove & Andreasen, 1985; Rochester et al., 1973). Patients’ impairments in

combining meaning with syntax had its greatest impact on processing the animacy/semantically violated sentences where, relative to nonviolated sentences, the attenuation in RT in patients failed to reach significance, even at the point of decision.

A relative insensitivity to the build-up of whole-sentence meaning could potentially lead to sentence processing being dominated by the semantic associative effects between single words in schizophrenia. The inappropriate intrusion of semantic relationships between individual words at the expense of conveying whole-sentence meaning is often seen in the speech produced by patients who are positively thought disordered (Andreasen, 1979a, 1979b, 1986; Bleuler, 1911/1950). However, unlike in our previous ERP study with the same stimuli (Kuperberg, Sitnikova, et al., 2006), the degree of RT insensitivity to any of these linguistic violations did not predict the degree of positive thought disorder. Although we do not wish to overinterpret this lack of a correlation, as the sample size and range of thought disorder in this patient cohort was relatively small, the absence of a relationship suggests that a relative insensitivity to linguistic violations is not specific to the symptom of thought disorder. Indeed, careful linguistic analyses reveal spoken language abnormalities even in patients who do not show clinical thought disorder: The speech produced is less complex than that of controls, as reflected by a higher percentage of simple sentences and, in compound sentences, by fewer deeply embedded clauses (Fraser, King, & Thomas, 1986; Morice & Ingram, 1982). Demands for integrating semantic with syntactic information are often maximal at points of syntactic complexity (Ferreira, 2003; Traxler, Morris, & Seeley, 2002) and ambiguity (MacDonald, Perlmuter, & Seidenberg, 1994; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Thus, it is possible that an impairment in combining syntactic and semantic information to build up context is characteristic of schizophrenia as a whole and that thought disorder manifests clinically only when this integration breaks down entirely such that language processing becomes dominated by semantic associations between individual words.

Conclusion and Future Directions

In sum, we have demonstrated that, relative to healthy controls, patients show a reduced attenuation of RT to morphosyntactic and

³ In our ERP study with the same stimuli, patients did show electrophysiological differences between animacy and morphosyntactically violations presented at the midsentence position (Kuperberg, Sitnikova, et al., 2006). Electrophysiological measures might detect slightly different neurocognitive processes from those detected by RTs. Indeed, ERP abnormalities do not necessarily map onto behavioral abnormalities with language stimuli in schizophrenia (Mathalon, Faustman, & Ford, 2002).

⁴ The group by sentence type interaction at sentence-final critical verbs reached significance on the items analysis but not on the subjects analysis. By considering each of the correctly answered trials as a random effect, the items analysis may have had more power than the subjects analysis to detect differences between patients and controls on critical verbs at the sentence-final position. One reason why the subjects analysis at sentence-final critical verbs may not have had as much power to detect between-groups differences as at sentence-final noncritical words or at decision is that, in controls, a tendency for RTs to increase to violations on critical verbs relative to nonviolated verbs (see pattern to midsentence critical verbs) may have been counteracted by a tendency for RTs to decrease at sentence-final positions of violated sentences relative to nonviolated sentences (see pattern to sentence-final noncritical words).

animacy/semantic violations at the ends of simple English sentences and at the point of making decisions about their acceptability. We suggest that semantic and syntactic components of the sentence processing system are relatively intact and that patients' main problem is in integrating these different sources of information to build up linguistic context.

Although the current study focuses on language, it will be interesting to determine whether an impairment in integrating different sources of information to build up a gestalt representation of meaning in schizophrenia is apparent in other domains. We are currently investigating this hypothesis by examining real-world comprehension in the visual domain (Sitnikova, Kuperberg, & Holcomb, 2003; Sitnikova, West, & Kuperberg, 2006). Finally, the current behavioral study paves the way toward understanding the neural basis of language disturbances in schizophrenia. The normal integration of semantics and syntax is dependent on a highly interactive system (Boland & Tanenhaus, 1991; MacDonald et al., 1994; Tanenhaus & Carlson, 1989; Trueswell & Tanenhaus, 1994) that involves fast parallel processing within widespread cortical and subcortical networks (Kuperberg, Holcomb, et al., 2003; Ullman, 2001). It is possible that the disconnection between various parts of this network observed in some studies of schizophrenia (Friston, 1998; Jennings, McIntosh, Kapur, Zipursky, & Houle, 1998), may, at the sentence level, result in an impairment of this fast integration of semantic and syntactic information in schizophrenia. Future studies using this paradigm with spatiotemporal functional neuroimaging techniques will test this hypothesis.

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