Stuttering and Natural Speech Processing of Semantic and Syntactic Constraints on Verbs

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Purpose: Previous findings from event-related brain potentials (ERPs) indicate that adults who stutter (AWS) exhibit processing differences for visually presented linguistic information. This study explores how neural activations for AWS may differ for a linguistic task that does not require preparation for overt articulation or engage the articulatory loop for silent speech.

Method: Syntactic and semantic processing constraints were examined in AWS and adults who are normally fluent (AWNf) by assessment of their behavioral performance and ERPs in a natural speech listening task.

Results: AWS performed similarly to AWNF in identifying verb-agreement violations and semantic anomalies, but ERPs elicited by syntactic and semantic constraints indicated atypical neural functions for AWS. ERPs of the AWNF displayed an expected N400 for reduced semantic expectations and a typical P600 for verb-agreement violations. In contrast, both N400s and P600s for the semantic and verb-agreement conditions were observed in the ERPs of the AWS.

Conclusions: The findings suggest that AWS may engage semantic–syntactic mechanisms more generally for semantic and syntactic processing. These findings converge with earlier studies using visual stimuli to indicate that whereas linguistic abilities are normal in AWS, underlying brain activity mediating some aspects of language processing may function differently.

KEY WORDS: verb-agreement, semantic anomalies, stuttering, language, ERPs

Stuttering is characterized by involuntary disruptions in the flow and rhythm of speaking even though the individual knows exactly what he/she wants to say. These uncontrolled interruptions in producing speech, commonly perceived as sound prolongations, syllable repetitions, and silent blocks, can be brief or can last for many seconds (Conture, 2001; Yairi & Ambrose, 2005). The foci of many earlier studies of stuttering were on speech motor control variables as they relate to overt fluent and nonfluent speech production and in many cases examined atypical motor activations in the articulatory, laryngeal, and respiratory systems (e.g., Denny & Smith, 1992; McClean & Runyan, 2000; Peters & Boves, 1988; Smith et al., 1993; Zimmerman, 1980; Zocchi et al., 1990). Although stuttering manifests as a disorder of overt speech production, it is becoming increasingly clear that other factors that interact with the development of the speech motor system play a role in its epigenesis. It has been hypothesized that stuttering cannot be attributed to a single cause but, rather, is the result of nonlinear interactions between a vulnerable speech motor system and a variety of factors that interact with the functioning of this system (Smith, 1990; Smith & Kelly, 1997). Some of these factors may include genetic predispositions, effects of emotional...
and autonomic arousal, and linguistic and other cognitive processing demands (Smith & Kelly, 1997). Converging evidence from a large body of literature indicates that the interactions between these variables in the development of stuttering will need to be uncovered for a more complete understanding of the disorder (e.g., Ambrose, Yairi, & Cox, 1993; Bossardt, Ballmer, & de Nil, 2002; Howell, 2004; Paden, Ambrose, & Yairi, 2002; Kleinnow & Smith, 2000; Ratner, 1997; Weber & Smith, 1990; Weber-Fox, 2001; Wolk, Edwards, & Conture, 1992; Yaruss, 1999; Zelaznik, Smith, Franz, & Ho, 1997).

Working within a framework in which multiple factors are thought to interact during development to contribute toward the emergence of stuttering, our research in recent years has focused on language processing as one of these factors. Kinematic and electromyography (EMG) findings indicate that compared with normally fluent adults, the speech motor coordination of adults who stutter (AWS) is more sensitive to increased linguistic demands, indicating an interaction between cognitive loads associated with language formulation and the motor control of speech (Kleinow & Smith, 2000; van Lieshout, Starkweather, Hulstijn, & Peters, 1995). The current study is in line with a series of experiments designed to examine how neural processes occurring during linguistic tasks differ between individuals who stutter and those who are normally fluent (Cuadrado & Weber-Fox, 2003; Weber-Fox, 2001; Weber-Fox, Spencer, Spruill, & Smith, 2004). These experiments tap more general language processing abilities of adults who stutter when their speech production systems are not engaged, rather when they are reading silently or listening to linguistic stimuli.

A growing body of evidence from brain imaging studies indicates that AWS exhibit atypical brain functions in perisylvian areas related to speech, language, and auditory processing. AWS displayed a hemispheric asymmetry characterized by overactivation of right cortical areas for speaking and for tasks that do not overtly engage the speech motor system (e.g., Braun et al., 1997; Fox et al., 1996, 2000; Ingham, Fox, Ingham, & Zamarripa, 2000; Preibisch et al., 2003). White matter volumes were observed to be reduced in left sensorimotor regions (Sommer, Koch, Paulus, Weiller, & Buchel, 2002), while increased white matter volumes were observed in right hemisphere perisylvian, prefrontal, and sensorimotor areas in adults who stutter (Jancke, Hanggi, & Steinmetz, 2004). Preibisch and colleagues (2003) interpreted the atypical hemisphere activity that they observed in the right frontal operculum during reading aloud and a silent semantic decision task as reflecting compensatory processes related to atypical functions in the left hemisphere. This interpretation was based on evidence of reduced white matter underlying the left sensorimotor cortex in the tongue and larynx regions in AWS (Sommer, Koch, Paulus, Weiller, & Buchel, 2002). Additionally, recent findings by Giraud et al. (2008) indicate that activity of the basal ganglia may be correlated with the severity of persistent stuttering. Functionally, frontotemporal and temporoparietal activations in the left hemisphere involving auditory functions were decreased in AWS, particularly during stuttering (Braun et al., 1997; Fox et al., 1996, 2000). Magnetoencephalography (MEG) findings in AWS further indicate atypical activation patterns in left perisylvian regions in preparation for speaking (Salmelin, Schnitzler, Schmitz, & Freund, 2000). In contrast to the sequence of activation observed in normally fluent speakers, the left inferior frontal area involved in speech planning became active after the rolandic areas involved in motor execution (Salmelin et al., 2000).

Recent findings from a MEG study of speech perception indicate that language processing in the auditory modality differs for AWS and adults who are normally fluent (AWNF). Biermann-Ruben, Salmelin, and Schnitzler (2005) examined neural activation during speech perception prior to overt repetition of a spoken word and sentence and a sentence transformation task. The speaking task was delayed 500 ms after the offset of the word or sentence in order to observe activation patterns during the speech perception phase. The findings indicated that compared with AWF, AWF had greater activation of left inferior frontal areas, thought to be important for speech preparation, during the temporal window of 95–145 ms postword and -sentence onsets. In addition, between 315 and 1,000 ms poststimulus, activations of the right rolandic areas—that thought to be involved in sensorimotor processing—were larger for single-word tasks compared with sentence tasks for the AWF, but the opposite pattern was seen for the AWS. These recent findings suggest that neural activation patterns of AWS differ from AWF during speech perception (Biermann-Ruben et al., 2005). However, because the speech perception phase was followed by a delayed speaking task, it is not known whether the differences in activation would occur even without requirements to prepare for overt articulation. A previous study in normally fluent adults that did not require speaking following speech perception did not elicit activation in the temporoparietal, inferior-frontal, and rolandic areas (Helenius, Salmelin, Service, & Connolly, 1998). Taken together, these findings suggest the possibility that the differences between the AWS and the AWF observed by Biermann-Ruben and colleagues could have been to some degree due to activations for preparing to speak. The current study extends the work of Biermann-Ruben and colleagues by using a natural speech processing paradigm that only requires a delayed button press for a sentence judgment task; thus, no preparation for overt articulation is necessary.

Earlier studies of language processing in AWS using measures of event-related brain potentials (ERPs)
revealed that language processing is subtly altered in AWS, even in the absence of overt speech production requirements (Cuadrado & Weber-Fox, 2003; Weber-Fox, 2001; Weber-Fox et al., 2004). These studies used visual language stimuli and revealed that despite possessing language abilities that are within normal limits, some neural processes peaking after 250 ms are atypical in AWS. Early-latency cortical potentials (N100, N180, P200)—thought to be more closely related to sensory, perceptual processes (Mangun & Hillyard, 1991)—did not distinguish AWS and AWNF (Cuadrado & Weber-Fox, 2003; Weber-Fox, 2001; Weber-Fox et al., 2004). In contrast, endogenous, longer-latency ERPs elicited in adults who stutter were characterized by reduced amplitudes. Both the N400 elicited by semantic anomalies and the late positivity (P600) elicited by verb-agreement violations were smaller in amplitude for AWS compared with AWNF. Thus, processes associated with integration of word meaning (indexed by the N400; e.g., Kutas & Hillyard, 1980) and syntactic re-analysis (indexed by the P600; e.g., Friederici, Hahne, & Mechlinger, 1996; Hagoort, Brown, & Groothusen, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995) point to processing differences in AWS for both semantic and syntactic constraints, despite solid language skills indexed by standardized measures.

In order to understand the significance of these processing differences, it will be necessary to determine whether atypical ERPs are due to underlying distinctions in processing linguistic constraints or whether they are due to processes mediating the conversion of orthographic symbols to phonological representations. Behavioral evidence suggests that reading involves phonological encoding of orthographic symbols for lexical access and may include processes of subvocal rehearsal or inner speech via an articulatory loop (Baddeley, 1992; Baddeley, Eldridge, & Lewis, 1981; Perfetti, 1999). Therefore, the question remains whether AWS process auditory language stimuli differently from AWNF. If the differences in neural functions observed in the visual studies were due primarily to silent “inner speech” processes (e.g., Baddeley, 1992), then natural speech may not elicit the same language processing differences. Converging evidence from the sentence processing ERP studies (Cuadrado & Weber-Fox, 2003; Weber-Fox, 2001) and findings from a visual rhyming study that manipulated orthographic and phonological congruence suggest that sentence processing constraints, rather than the reading of pairs of words, elicit more robust differences in ERPs between AWS and AWNF (Weber-Fox et al., 2004). These findings suggest that processing differences between AWS and AWNF are the result of interactions between multiple factors that are likely to include language constraints and cognitive loading (Bosshardt, Ballmer, & de Nil, 2002; Weber-Fox et al., 2004). The current study was designed to investigate how AWS process auditory language stimuli, thus excluding the need for phonological encoding of grapheme symbols and the engagement of the “inner speech” articulatory loop. If differences in language processing for AWS include functions other than (or in addition to) those associated with the encoding of orthographic symbols, then their ERPs elicited by the natural speech stimuli should also display atypical patterns.

Therefore, we used a natural speech, sentence processing paradigm in the current study to examine both semantic and syntactic constraints. Further, the critical words for analysis were the verbs in each of the conditions. This allowed us to examine both semantic and syntactic processing for the same word class—verbs—at the same point in each sentence. It has been suggested that the use of verbs may be particularly challenging for young children who stutter, and recent evidence indicates that these children may lag in the number of different verbs and total number of verbs produced in spontaneous speech (Wagovich & Ratner, 2007). Similar to nouns, verbs are conceptually rich and provide semantic information in a sentence, but in addition, they provide relational information for integrating inflections and argument structures across the sentence (Hirsh-Pasek & Golinkoff, 2006; Langacker, 1987; Osterhout, Kim, & Kuperberg, in press). Verb processing engages distinctive neural activations compared with nouns as indexed by measures of ERPs and functional magnetic resonance imaging (fMRI) in both children and adults (Federmeier, Segal, Lombrozo, & Kutas, 2000; Weber-Fox, Hart, & Spruill, 2006; Yokoyama et al., 2006). In a study using class-ambiguous verbs/nouns (e.g., drink, smoke, hammer), Federmeier and colleagues (2000) noted that the role of words in a given context impacts the neural activations for processing that word. It has been suggested that verbs should engage syntactic and semantic processing streams (Osterhout et al., in press). Accordingly, the design of the current study allows for comparison of syntactic and semantic processing in AWS for the same critical verbs across conditions.

In summary, the current study builds on previous findings that suggest language processing differences between AWS and AWNF. Further, the design of the study allows us to explore the neural functions elicited for linguistic processing in the absence of preparation for overt articulation and/or engaging the internal articulatory loop. In addition, the focus on verbs as the critical comparative words across conditions provides indices of both syntactic and semantic constraints at the same point in sentence processing. Finally, using natural speech stimuli (auditory modality) enables us to determine whether previously described differences in language processing are modality specific or whether AWS exhibit differences in brain functions related specifically to linguistic operations.
Method
Participants and Screening Procedures

Participants were 9 AWS and 9 AWNF between the ages of 18 and 45 years. Participants were matched according to age, gender, and educational background (see Table 1). All AWS reported a history of developmental, childhood stuttering. All participants were right handed, as determined by the Edinburgh Inventory for assessment of handedness (Oldfield, 1971) and were native English speakers with no reported history of neurological, language, reading, or hearing impairments. Stuttering behaviors were verified during administration of the Stuttering Severity Instrument for Children and Adults–Third Edition (SSI-3; Riley, 1994), in which the behaviors were videorecorded, and during interactions over the course of the experiment. The SSI-3 was administered by speech-language pathology graduate students who had clinical training in stuttering and who were supervised by a certified speech-language pathologist.

The language abilities of the participants were assessed, and all participants scored within normal limits on four subtests of the Test of Adolescent and Adult Language–Third Edition (TOAL-3; Hammill, Brown, Larsen, & Wiederholt, 1994), including the listening and speaking grammar and vocabulary subtests. The composite standard scores for the four subtests are displayed in Table 2 for the AWS and the AWNF: Group Standard Scores, $F(1, 16) < 1$. All participants also exhibited normal hearing in each ear as confirmed by hearing screening at a level of 30 dB HL at 500, 1000, and 2000 Hz presented via headphones. Also, each participant demonstrated normal or corrected-to-normal vision as measured by a visual acuity screening of each eye using a standard eye chart.

Stimuli for the Sentence Processing Task

The stimuli were 180 naturally spoken sentences produced by a female speaker and digitized at a rate of 16 kHz. For each word up to and including the critical word (verb), the visual display of the auditory waveform was used to pick the onsets and offsets and then was perceptually checked to make sure the word was not clipped (using CoolEdit Pro software). The .wav files for each word, converted to sound files, were then presented (via the Neuroscan STIM program) with a 50-ms interval interjected between each word, up to and including the word following the critical verb comparison. Thus, onsets of each word were clearly discernable while maintaining a natural-sounding rate, rhythm, and prosody. The sentence stimuli consisted of three conditions. In all cases, the verb was the critical word. The conditions included a control (e.g., “Every day, the children pretend to be superheroes”), a verb agreement violation (e.g., “Every day, the children *pretends to be superheroes”), and a semantically unexpected verb (e.g., “Every day, the children *rust to be superheroes”). Sample sentence stimuli are listed in the Appendix. These sentences were designed so that all the words leading up to the critical word (the verb) were identical across the three conditions—thus enabling the ERPs elicited by the verbs in each condition to be directly compared. Also, the sentences were counterbalanced in the following ways: First, half of the

Table 1. Characteristics of participants.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Adults who stutter</th>
<th>Adults who are normally fluent</th>
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<tbody>
<tr>
<td></td>
<td>Age</td>
<td>Gender</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>2</td>
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<td>3</td>
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<td>8</td>
<td>43</td>
<td>M</td>
</tr>
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<td>9</td>
<td>26</td>
<td>M</td>
</tr>
<tr>
<td>M</td>
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</tr>
<tr>
<td>SE</td>
<td>2.93</td>
<td>0.60</td>
</tr>
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Note. Education levels: 1 = high school graduate, 2 = one yr college, 3 = two yrs college, 4 = three yrs college, 5 = four yrs college, 6 = first year graduate school, 7 = master’s degree completed. yr = year.

Table 2. Standard scores for the Test of Adolescent and Adult Language–Third Edition (TOAL-3).

<table>
<thead>
<tr>
<th>Participant</th>
<th>Adults who stutter</th>
<th>Adults who are normally fluent</th>
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<tbody>
<tr>
<td></td>
<td>Standard score</td>
<td>%</td>
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<tr>
<td>2</td>
<td>107</td>
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<td>3</td>
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<td>9</td>
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<td>81</td>
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<td>M</td>
<td>104.89</td>
<td>62.11</td>
</tr>
<tr>
<td>SE</td>
<td>7.13</td>
<td>17.47</td>
</tr>
</tbody>
</table>

Note. Standard scores were calculated from a composite of four subtests of the TOAL-3: Listening Vocabulary, Speaking Vocabulary, Listening Grammar, and Speaking Grammar.
noun subjects in the sentences were singular and half were plural, and second, each word that served as a control verb also served as a semantically unexpected verb in another sentence. For the semantic condition, the critical word (the verb) does not produce a frank anomaly in many cases but, rather, is unexpected. This is an attribute of verbs; unlike nouns, they are quite flexible in usage. However, as the sentence continues, it becomes clear that the meaning of the verb is incorrect. For example, “Everyday the ballerina submerges on her pointed toe shoes.” The ERP measures at the point of the verb, therefore, do not reflect the additional semantic information provided by the completion of the sentence. So the ERPs elicited by the verbs across the three conditions reflect processing of identical information leading up to the verb, and the additional information following the verb does not confound a comparison of the ERP measures across the three conditions.

**Electroencephalographic Recordings**

Electrical activity at the scalp was recorded from electrodes secured in an elastic cap (Quik-cap, Compumedics Neuroscan, Charlotte, NC). Twenty-eight electrodes were positioned over homologous locations of the two hemispheres according to the criteria of the International 10-10 system (American Electroencephalographic Society, 1994). Locations were as follows: lateral sites F7/F8, FT7/FT8, T7/T8, TP7/TP8, P7/P8; mid-lateral sites FP1/FP2, F3/F4, FC3/FC4, CP3/CP4, P3/P4, O1/O2; and midline sites FZ, FCZ, CZ, CPZ, PZ, OZ. Recordings were referenced to linked electrodes placed on the left and right mastoids. Horizontal eye movement was monitored via electrodes placed over the left and right outer canthi. Electrodes over the left inferior and superior orbital ridge were used to monitor vertical eye movement. All electrode impedances were adjusted to 5 kohms or fewer. The electrical signals were amplified within a bandpass of .1 and 100 Hz and were digitized online (Neuroscan 4.0) at a rate of 500 Hz.

**Procedure**

Each participant completed the informed consent forms and medical/case history forms. All participants were encouraged to ask questions. Once appropriate impedance levels were obtained, the participants were seated comfortably in a sound-attenuating room and were positioned 160 cm from a 47.5-cm monitor. The experimental task was explained, and headphones were positioned over the electrode cap.

Participants were instructed to listen to each of the sentences and to judge whether each sentence was a good English sentence and made sense. They were also asked to refrain from blinking during trials. As the experiment was self-paced, the participant triggered the beginning of a trial with a button press. A fixation point appeared on the screen and, following a delay of 1,000 ms, the sentence was presented binaurally through headphones at 70–75 dB SPL. Following the presentation of the sentence, there was a delay of 500 ms, followed by a “Yes/No?” presented on the screen to cue the participant to press the “Yes” button if the sentence was a good English sentence and made sense. Otherwise, they were instructed to press “No.” The response hands corresponding to the “Yes” and “No” buttons were counterbalanced across participants and gender and within each of the groups. The sentence stimuli were presented in 5 blocks with 36 sentences in each block. The sentences were pseudorandomized so that each condition was equally represented in all blocks. Because the task was self-paced, the time for completion varied across participants (between approximately 45 and 55 min).

**Data Analyses**

**Behavioral measures.** Sentence judgment accuracy was obtained from signals generated by the response pad. Sentence judgment accuracies for each participant in each condition were compared using mixed effects analyses of variance (ANOVAs) with repeated measures that included a between-subjects factor (group: AWS, AWNF) and a within-subject factor (condition: control, verb-agreement violation, semantic). Using the mean-square error terms of the repeated measures analysis, post hoc comparisons were made using the Tukey’s honestly significant difference (HSD) method to determine which comparisons contributed to significant effects (Hays, 1994).

**ERP measures.** Trials with excessive eye movement or other forms of artifact (29%) were excluded from further analyses of the ERP responses. The rejected trials were equally distributed across the three conditions. The remaining trials were averaged by condition for each participant. The averages were triggered 100 ms prior to the verb in each sentence and included 1,500-ms post-stimulus onset. The ERP data from the 100-ms interval prior to the prime and target onsets served as the baseline activity. The peak latencies of ERP components were computed in relation to the trigger point (0 ms) that marked the verb onsets. The peak latencies and peak and mean amplitudes were automatically detected using Neuroscan 4.2 software within specified temporal windows that captured the ERP components elicited in this paradigm, as described in the following paragraph.

For ERPs elicited by the verbs in each of the three conditions, the peak and mean amplitudes and peak latencies of the N400 were measured within the temporal window of 300–550 ms post-stimulus onset. The mean amplitude of the later, broader positive component (P600) was measured within the temporal window of...
850–1,150 ms. ERP peak and mean amplitudes and peak latencies were compared with mixed effects ANOVAs with repeated measures. For analyses of the ERP responses elicited at lateral and midlateral electrode sites, ANOVAs with repeated measures included a between-subjects factor of group (AWS, AWNF) and three within-subject factors including condition (control, verb-agreement violation, semantic), hemisphere (left and right), and electrode site (FC3/4, T7/8, TP7/8, C3/4, CP3/4, P3/4). For analyses of ERPs elicited at midline sites, the repeated measures ANOVAs included a between-subjects factor of group (AWS, AWNF) and two within-subject factors including condition (control, verb-agreement violation, semantic) and electrode site (FCZ, CZ, CPZ, PZ, OZ). The subset of electrode sites used for the comparisons provided a distribution of sampling from anterior to posterior midline sites in addition to sites over the left and right hemispheres where reliable peaks could be measured. Significance values were set at $p < .05$. For all repeated measures with greater than 1 degree of freedom in the numerator, the Huynh-Feldt (H-F) adjusted $p$ values were used to determine significance (Hays, 1994). The effect sizes, indexed by the partial eta squared statistic ($\eta^2$), are reported for all significant effects. Interactions involving group (H-F $p < .08$) were followed up with step-down ANOVAs for each group to determine effects specific to the AWNF and AWS. These repeated measures ANOVAs did not include a between-subjects factor. Tukey’s HSD post hoc comparisons, which use the MS error term from the repeated measures ANOVA, were calculated for significant interactions involving multiple variables to determine which comparisons contributed to the significant $F$ values (Hays, 1994).

## Results

### Sentence Judgment Accuracy

The AWS and the AWNF performed with high and similar accuracy on the detection of verb-agreement and semantic violations, $F(1, 16) = 1.143, p = .301$. The effect of condition, $F(2, 32) = 9.927, H-F p = .001, \eta^2_p = .383$, revealed that the accuracy in detecting verb-agreement violations was reduced relative to the control and semantic conditions for all the participants combined, Tukey’s HSD, $p < .05$. As can be seen in Figure 1, mean accuracy appeared reduced for the AWS in the control condition; however, the Group × Condition interaction did not reach significance, $F(2, 16) = 2.518, H-F p = .11$.

### ERPs

The grand average ERPs elicited by the verbs in the three sentence conditions are illustrated in Figures 2 and 3 for the AWNF and the AWS groups, respectively. As anticipated on the basis of earlier studies (e.g., Friederici et al., 1993), the verbs in the control, verb-agreement, and semantic conditions elicited distinct waveforms in the AWNF. The N400 elicited in the semantic condition and the P600 elicited in the verb-agreement condition for the AWNF can be observed in Figure 2. Figure 3 illustrates the N400 and P600 responses elicited in the AWS. The similarities and differences of the N400 and P600 across the conditions and groups are summarized in the paragraphs that follow.

**N400.** The mean (SE) peak latency of the N400 component was 414.2 ms (7.3) over lateral/midlateral sites and 409.8 ms (8.4) over midline sites. There were no significant effects of condition or Condition × Group interactions on the peak latency of the N400 measured over the lateral/midlateral and midline electrode sites, $F(2, 32) < 1$.

The semantic condition elicited larger peak and mean N400 amplitudes compared with the control condition for lateral/midlateral sites, $F(2, 32) = 5.229, H-F p = .011, \eta^2_p = .246$, $F(2, 32) = 3.304, H-F p = .057, \eta^2_p = .171$, and for midline sites, $F(2, 32) = 6.950, H-F p = .003, \eta^2_p = .303, F(2, 32) = 5.339, H-F p = .014, \eta^2_p = .250$ (Tukey’s HSD $p < .05$). Although the N400 peak and mean amplitude measures did not result in overall group differences for lateral/midlateral or midline sites, $F(1, 16) < 1$, there was a consistent trend for Condition × Group interaction for the peak and mean amplitude measures of lateral/midlateral sites, $F(2, 32) = 2.697$,
Figure 2. Grand average event-related brain potentials (ERPs) elicited by the control, verb agreement, and semantic conditions for the AWNF group. This figure illustrates the ERPs from midline electrode sites and from lateral/midlateral sites over the left and right hemispheres included in the statistical analyses. Negative potentials are plotted upward. The grand averages for the AWNF show distinctions in the waveforms elicited by each of the three conditions, including a clear N400 for the semantic condition and a robust P600 for the verb-agreement condition.

H-F $p = .08, \eta^2_p = .144, F(2, 32) = 2.845, H-F p = .08, \eta^2_p = .151$, and midline sites, $(2, 32) = 2.791, H-F p = .08, \eta^2_p = .149, F(2, 32) = 2.890, H-F p = .08, \eta^2_p = .153$. In Figure 4, the peak and mean amplitudes of the N400s are plotted for both groups across conditions to illustrate the nature of these Condition × Group interactions.

Step-down ANOVAs confirmed that for the AWNF, the mean amplitudes of the N400 at midline electrode sites were larger, $F(2, 16) = 5.994, H-F p = .011, \eta^2_p = .428$, for the semantic condition compared with both the control (Tukey’s HSD $p = .019$) and verb-agreement (Tukey’s HSD $p = .025$) conditions (see Figure 4). A similar pattern was observed for the peak amplitude N400 measures of midline sites, $F(2, 16) = 3.901, H-F p = .042, \eta^2_p = .326$, with post hoc results indicating a tendency for the N400 peak amplitude to be larger for the semantic condition compared with the N400 elicited by the control and verb-agreement conditions (Tukey’s HSD $p < .07$). The peak and mean amplitudes of the N400 for AWNF at lateral/midlateral sites also tended to be larger for the semantic condition compared with the N400 elicited in the control condition, $F(2, 16) = 3.442, H-F p = .055, \eta^2_p = .304$ (Tukey’s HSD $p < .08$). In summary, the N400 amplitudes elicited in the AWNF were, as expected, larger for the semantic condition compared with the control and verb-agreement conditions.

Step-down ANOVAs for the AWS presented an unexpected pattern for the N400 amplitudes. The condition effects for the mean amplitude measures at midline electrode sites did not reach significance, $F(2, 16) = 2.456, H-F p = .141, \eta^2_p = .235$. However, a significant condition effect for the peak amplitude measures of the N400 at midline electrode sites for the AWS, $F(2, 16) = 6.076, H-F p = .015, \eta^2_p = .432$, revealed that the N400 amplitude was larger for the semantic and verb-agreement conditions relative to the control, Tukey’s HSD, $p < .03$ (see Figure 4). Further, the N400 peak amplitudes elicited by
the semantic and verb-agreement conditions were not different, Tukey’s HSD $p = .94$. The mean amplitude measures for the N400 at lateral/midlateral sites did not reach significance, $F(2, 16) = 2.364$, H-F $p = .146$, $\eta^2_p = .228$. However, a significant condition effect for the N400 peak amplitudes at lateral/midlateral sites, $F(2, 16) = 4.981$, H-F $p = .021$, $\eta^2_p = .384$, revealed that the N400 peak amplitude was larger for the verb-agreement violation relative to the control (Tukey’s HSD $p = .017$), a comparison that did not reach significance for the N400 elicited by the semantic condition (Tukey’s HSD $p = .133$). Once again, there were no differences between the N400 peak amplitudes elicited by the semantic and verb-agreement conditions (Tukey’s HSD $p = .55$). In summary, unlike the ERPs of the AWNF that displayed a unique N400 amplitude increase for the semantic condition, the N400 amplitudes of the AWS were not distinguishable for the semantic and verb-agreement conditions. Instead, a significant N400 peak amplitude increase was elicited by the verb-agreement and semantic conditions relative to the control at the midline electrode sites; whereas at lateral/midlateral electrode sites, only the verb-agreement violations elicited a significantly larger N400 peak amplitude compared with the control condition.

$P600$. Measures of the mean amplitudes of the P600, illustrated in Figure 5, revealed an effect of condition for both the lateral/midlateral electrode sites, $F(2, 32) = 8.329$, H-F $p = .001$, $\eta^2_p = .342$, and midline sites, $F(2, 32) = 15.689$, H-F $p < .0001$, $\eta^2_p = .495$. Post hoc comparisons for the mean amplitude measures at lateral/midlateral and midline electrodes sites revealed that the verb-agreement condition elicited a larger amplitude P600 compared with the control (Tukey’s HSD $p < .003$) and semantic conditions (Tukey’s HSD $p < .005$).

The mean amplitudes of the P600 did not result in overall group differences, $F(1, 16) < 1.322$, H-F $p > .266$. However, group interacted significantly with condition for the mean amplitude measures for both the lateral/midlateral sites, $F(2, 32) = 4.276$, H-F $p = .02$, $\eta^2_p = .211$, and midline sites, $F(2, 32) = 5.496$, H-F $p = .009$, $\eta^2_p = .256$. Figure 5 illustrates the nature of these Condition × Group interactions.

Figure 3. Grand average ERPs elicited by the control, verb-agreement, and semantic conditions for the AWS group. This figure illustrates the ERPs from midline electrode sites and from lateral/mid-lateral sites over the left and right hemispheres included in the statistical analyses. Negative potentials are plotted upward.
Step-down ANOVAs revealed that for the AWNF, the mean amplitudes of the P600 at midline electrode sites were larger for the verb-agreement condition, $F(2, 16) = 15.343$, $H-F p < .001$, $\eta^2_p = .657$, compared with both the control (Tukey’s HSD $p = .018$) and semantic (Tukey’s HSD $p = .0003$) conditions (see Figure 5). In addition, the mean amplitudes of the P600 for AWNF at lateral/midlateral sites were larger for the verb-agreement condition compared with the control condition, $F(2, 16) = 7.898$, $H-F p = .004$, $\eta^2_p = .497$, Tukey’s HSD, $p = .003$. The P600 mean amplitudes at the lateral/midlateral electrode sites for the verb-agreement condition also tended to be larger than the P600 elicited in the control condition (Tukey’s HSD $p = .10$). Thus, for the AWNF, as expected, the verb-agreement violation elicited a larger amplitude P600 compared with the control (midline electrode locations) and semantic conditions (midline and lateral/midlateral electrode locations).

In contrast, follow-up ANOVAs for the AWS presented a somewhat surprising pattern for the P600 amplitudes (see Figure 5). Significant condition effects for the mean amplitude measures at midline electrode sites, $F(2, 16) = 7.037$, $H-F p = .006$, $\eta^2_p = .468$, revealed that the P600 amplitude was larger for the verb-agreement violation compared with the control condition (Tukey’s HSD $p = .005$); however, the P600 amplitudes elicited by the semantic and verb-agreement conditions were not different (Tukey’s HSD $p = .12$). The mean amplitude measures for the P600 at lateral/midlateral sites followed a similar pattern. The significant condition effects, $F(2, 16) = 4.560$, $H-F p = .047$, $\eta^2_p = .363$, revealed a larger P600 elicited by the verb-agreement violation compared with the control condition (Tukey’s HSD $p = .025$). Once again, there were no differences between the P600 peak amplitudes elicited by the semantic and verb-agreement conditions (Tukey’s HSD $p = .68$). In summary, unlike the ERPs of the AWNF that displayed a typical P600 amplitude increase for the verb-agreement violation condition (and not for the semantic condition), the P600 amplitudes of the AWS were not distinguishable for the semantic and verb-agreement conditions. Instead, the P600 amplitude...
elicited for the semantic condition was not different from the control or verb-agreement conditions.

Discussion

A natural speech processing paradigm was used with AWS to examine whether previously described differences for semantic and syntactic processing of visual stimuli were also present for auditorily presented stimuli. AWS performed similarly to AWNF in identifying verb-agreement violations and semantic anomalies. However, the cognitive processes involved in the processing of syntactic and semantic constraints, as indexed by the N400 and P600 ERPs, indicated that the neural functions mediating these tasks differ for a significant proportion of AWS. These findings converge with results in the visual modality to indicate that although AWS display linguistic abilities that are within normal limits on standardized tests of language abilities, the underlying brain activity mediating some aspects of language processing is atypical for a significant number of individuals in this population, even in the absence of preparation for overt speaking. These results are compatible with recent MEG findings that indicate differences in neural activations for speech perception in adults who stutter (Biermann-Ruben et al., 2005).

Modality-Specific Effects

The current findings for language processing in the auditory modality reveal underlying distinctions between AWS and AWNF that are qualitatively different from those observed for visual language processing studies (Cuadrado & Weber-Fox, 2003; Weber-Fox, 2001; Weber-Fox et al., 2004) and provide new insights into possible language processing differences between AWS and AWNF. Language processing in the visual modality requires conversion of orthographic symbols into phonological representations and may tap into “articulatory loop” mechanisms not involved for processing in the auditory modality (Baddeley, 1992). The current findings extend the previous work to indicate that AWS exhibit atypical neural activation patterns for language processing even without the additional cognitive load of engaging neural functions that may be involved in “inner speech” when reading. Therefore, differences in language processing between AWS and AWNF are not limited to the visual modality.

The differences observed for ERPs elicited by natural speech processing are, however, qualitatively different. Also, unlike findings for verb-agreement violations presented visually in an ERP paradigm (Cuadrado & Weber-Fox, 2003), the behavioral measures for the auditory sentences were similar for AWS and AWNF. Thus, the results from the current study indicate that some aspects of the behavioral and ERP differences between AWS and AWNF in visual language studies may have been specific to the encoding requirements of reading. However, given the results of the current study, it is clear that AWS exhibit more general language processing differences as well, despite language skills that are within the normal range as indexed by standard language testing.

Semantic and Syntactic Constraints

Normally fluent speakers. These sentences allowed us to examine differences between semantic and syntactic constraints imposed on the processing of the verbs in each sentence. The AWNF displayed robust N400 responses to the verbs that were semantically unexpected. Although the meanings of the verbs did not pose a frank semantic violation at the point in the sentence when the verbs were being processed (e.g., “you could imagine a cartoon horse singing”), the verbs in this condition were unusual and low probability. On the basis of previous literature, a relatively small but significant N400, as observed in the current study, would be expected because the amplitude of the N400 indexes ease of semantic integration (e.g., Friederici, Pfeifer, & Hahne, 1993; Fedemeier et al., 2000; Kutas & Hillyard, 1980). In contrast, the verb-agreement violation did not elicit an N400 in the AWNF. Instead a late positivity, known as a P600, characterized the verb-agreement condition. Again, this finding for the AWNF is consistent with previous reports of the P600 indexing syntactic re-analysis (e.g., Friederici et al., 1996; Hagoort et al., 1993; Neville et al., 1991; Osterhout & Holcomb, 1992). Thus, for the normally fluent speakers, an unexpected verb in these simple sentences did not trigger the need for syntactic re-analysis and repair (as indexed by the P600), and the verb-agreement violation did not impose greater difficulty in semantic integration (as indexed by the N400). Rather, for the AWNF, the ERPs elicited by the semantic and syntactic conditions engaged processing streams that were specific to the constraints being challenged.

AWS. The unexpected verbs in the semantic condition elicited N400 responses in AWS similar to those of AWNF, suggesting a similar increase in difficulty with semantic integration. However, a surprising finding for this group was that the verb-agreement violation also elicited an N400, suggesting that the anomalous morphological ending (presence or absence of the “s”) also increased difficulty in semantic integration. The verb-agreement violations also elicited a P600, indicating that this increased difficulty in semantic integration was followed by the more typical syntactic re-analysis process. For the semantic condition, the P600 was not significantly different from the control condition but also was not different from the P600 elicited by the verb-agreement
violation, thus falling somewhere in between the two conditions. Therefore, the general pattern for the AWS reflects a less differentiated processing system compared with their normally fluent peers in that the semantic and syntactic constraints elicited both N400 and P600 components for relatively uncomplicated violations of simple sentences.

It could be argued that it is not surprising that the verb stimuli in the current study elicited a more biphasic pattern (N400-P600) in AWS. As reviewed by Osterhout et al. (in press), the processing of verbs should engage both the semantic and syntactic processing streams because verbs are conceptually and semantically rich while providing relational information for syntax. However, it is not clear why the AWS would engage these processing streams less selectively compared with AWNF. One possibility is that the processing of verbs imposes a greater cognitive load for AWS. From the developmental literature, it is clear that verbs impose high processing loads for sentence comprehension and include integrating inflections and argument structures (Hirsh-Pasek & Golinkoff, 2006). Further, ERP evidence in school-age children indicates that verbs elicit one of the longest peak latencies of the second negative component, thought to index the initial availability of the word’s lexical category (Brown, Hagoort, & Ter Keurs, 1999), compared with other categories such as nouns and conjunctions (Weber-Fox et al., 2006). Further, errors in comprehension and production of verbs are common in children with specific language impairments, and it has been argued that these children have particular difficulty with the additional grammatical complexity that verbs require for sentence processing (Leonard, 1998; Leonard & Deevy, 2003). Recent evidence from language sample analyses indicate that verbs may create a greater challenge for young children who stutter compared with their typically developing peers (Wagovich & Ratner, 2007). Additionally, verb morphological complexity was observed to increase stuttering rates for some children and adults who stutter (Marshall, 2005). The current findings suggest that these early differences in verb usage proficiency may be reflected in adulthood by these more subtle measures of processing semantic and syntactic constraints on verbs. Future ERP studies in children who stutter are needed to explore the nature of the relationships between developmental differences in language abilities at early stages of stuttering and neural online-processing patterns elicited by linguistic stimuli.

The current finding of a biphasic N400-P600 response in AWS may indicate that the disorder of stuttering may be associated with a processing strategy that is only seen for more complex sentence processing in normally fluent adults. Recent investigations of language processing in typically developing adults have revealed that N400 and P600 can reflect the interface between semantic and syntactic processing under conditions that require complex online linguistic operations (e.g., Friederici & Frisch, 2000; Kemmerer, Weber-Fox, Price, Zdansczk, & Way, 2007; Kim & Osterhout, 2005; Kolk, Chwilla, van Herten, & Oor, 2003; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007). For example, Friederici and Frisch (2000) observed that thematic role violations were primarily semantic (elicited an N400) and violations of the type of verb arguments were syntactic (elicited a P600). However, a violation in the number of verb arguments (intransitive verb occurred with two arguments) elicited semantic processes followed by syntactic re-analysis and repair (biphasic N400-P600 combination). The findings of Friederici and Frisch (2000) indicated that during sentence processing, the structural and thematic information encoded by the verb is checked against the information that has been formed online. Their findings demonstrate that the degree of engagement of semantic and syntactic processing operations for normal speakers is fluid and depends on the type of linguistic information that must be integrated for continuing to process the sentence. The results from the current study suggest that when processing the information provided by verbs, the processing systems of AWS may be less fluid. That is, the AWS may engage the semantic and syntactic processing streams less efficiently for relatively simple violations that elicit more selective activation patterns in AWNF.

Conclusions

ERPs provide a functional measure of neural activity with fine temporal resolution (Nunez, 1995) and allow the examination of specific operations of language processing (e.g., King & Kutas, 1995; Kutas & Hillyard, 1980; Neville, et al., 1991; Osterhout & Holcomb, 1992; Weber-Fox, et al., 2006). The converging evidence from the current study and from the prior series of ERP studies in AWS (Cuadrado & Weber-Fox, 2003; Weber-Fox, 2001; Weber-Fox et al., 2004) indicates that stuttering is associated with differences in language processing activations, even in the absence of overt-speech planning and production. Our results are compatible with multifactorial models of stuttering (e.g., Smith, 1990; Smith & Kelly, 1997) and indicate that the disorder with its associated differences in brain morphology impacts not only the coordination of the speech-motor system but also may be reflected in the efficiency of operations related to the integration and differentiation of semantic and syntactic streams involved in language processing.

Notably, stuttering is a developmental disorder, and the differences we observe for language processing in AWS may not reflect processing that distinguishes young children who stutter from their typically developing peers. In a recent study of school-age children who stutter...
(Weber-Fox, Spruill, Spencer, & Smith, 2008), the behavioral and ERP differences between children who stutter compared with their normally fluent peers were qualitatively different and much more pronounced than those in AWS observed in an earlier study from our laboratory (Weber-Fox et al., 2004). These findings reinforce the need for developmental stuttering research. Therefore, as a follow-up to the current study, it will be necessary to study syntactic and semantic processing in children who stutter to gain a better understanding about how neural functions for language processing may contribute to the development of the disorder.

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References


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**Appendix.** Sample of stimulus sentences.

**Correct verb (verb agreement violation, reduced semantic expectation)**

1. Every day, the horses *gallop* (gallops, sing) to the top of the hill.
2. Every day, the canaries *sing* (sings, gallop) at the top of their lungs.
3. Every day, the secretary *types* (type, grazes) many legal documents.
4. Every day, the cow *grazes* (graze, types) along the fence line.
5. Every day, the ballerina *dances* (dance, submerges) on her pointed toe shoes.
6. Every day, the submarine *submerges* (submerge, dances) to a depth of 500 feet.
7. Every day, the beauticians *style* (styles, slither) at least 30 heads.
8. Every day, the snakes *slither* (slithers, style) through the fallen leaves.
Stuttering and Natural Speech Processing of Semantic and Syntactic Constraints on Verbs

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