Research Article

Semantic and Phonological Encoding Times in Adults Who Stutter: Brain Electrophysiological Evidence

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Purpose: Some psycholinguistic theories of stuttering propose that language production operates along a different time course in adults who stutter (AWS) versus typically fluent adults (TFA). However, behavioral evidence for such a difference has been mixed. Here, the time course of semantic and phonological encoding in picture naming was compared in AWS ($n = 16$) versus TFA ($n = 16$) by measuring 2 event-related potential (ERP) components: NoGo N200, an ERP index of response inhibition, and lateralized readiness potential, an ERP index of response preparation.

Method: Each trial required a semantic judgment about a picture in addition to a phonemic judgment about the target label of the picture. Judgments were mapped onto a dual-choice (Go–NoGo/left–right) push-button response paradigm. On each trial, ERP activity time-locked to picture onset was recorded at 32 scalp electrodes.

Results: NoGo N200 was detected earlier to semantic NoGo trials than to phonemic NoGo trials in both groups, replicating previous evidence that semantic encoding generally precedes phonological encoding in language production. Moreover, N200 onset was earlier to semantic NoGo trials in TFA than in AWS, indicating that semantic information triggering response inhibition became available earlier in TFA versus AWS. In contrast, the time course of N200 activity to phonemic NoGo trials did not differ between groups. Lateralized readiness potential activity was influenced by strategic response preparation and, thus, could not be used to index real-time semantic and phonological encoding.

Conclusion: NoGo N200 results point to slowed semantic encoding in AWS versus TFA. Discussion considers possible factors in slowed semantic encoding in AWS and how fluency might be impacted by slowed semantic encoding.

Stuttering is a childhood fluency disorder that persists in approximately 1% of adults (Yairi & Ambrose, 2013). Speech motor control interventions can improve fluency in adults who stutter (AWS; Bothe, Davidow, Bramlett, & Ingham, 2006), but gains are often limited (McClure & Yaruss, 2003). The ability to produce speech fluently is driven not only by speech motor control but also by efficient language production. An open question is whether the time course of language production differs in AWS versus typically fluent adults (TFA).

Language production involves the activation, selection, and phonological encoding of words conveying target concepts. Picture naming can be used to model and test the time course of these processes (Glaser, 1992). In picture

naming, visual feature processing of a pictured object leads to the activation of concepts (Collins & Loftus, 1975). Activation also spreads from concepts to lemmas containing syntactic information about specific words (Levelt, 1989). These processes generally relate to semantic encoding. From lemmas, activation spreads to lexemes, which contain whole-word sound properties of words, and then to phonemes containing segmental information necessary to drive articulation (Levelt, Roelofs, & Meyer, 1999). These processes generally relate to phonological encoding. Processes in semantic and phonological encoding unfold in just hundreds of milliseconds (Schmitt, Münte, & Kutas, 2000; van Turenhout, Hagoort, & Brown, 1997, 1998). Semantic encoding typically begins before phonological encoding (Levelt et al., 1999). However, these processes are not strictly serial, that is, semantic encoding does not necessarily terminate before phonological encoding begins (Dell & O'Seaghdha, 1992; Rahman & Sommer, 2003; Rahman, Van Turenhout, & Levelt, 2003). Rapid processing of semantic and phonological information facilitates fluent speech production (Levelt, 1989).

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Psycholinguistic theories of stuttering propose that the time course of processes in language production may differ in AWS versus TFA (Karniol, 1995; Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993; Wingate, 1988). Relying on behavioral measures, mixed insight has emerged about the time course of semantic and phonological encoding in AWS. As proposed below and elsewhere (Maxfield et al., 2016; Maxfield, Huffman, Frisch, & Hinckley, 2010; Maxfield, Morris, Frisch, Morphew, & Constantine, 2015; Maxfield, Pizon-Moore, Frisch, & Constantine, 2012), brain event-related potentials (ERPs) can shed additional light on real-time language production in AWS. The aim of this study was to compare the time course of semantic and phonological encoding in AWS versus TFA using ERPs.

Semantic and Phonological Encoding Times in AWS: Existing Evidence

To date, a few studies have provided evidence about the time course of semantic encoding in AWS. Studies requiring participants to produce names in the context of semantic interference (Hennessey, Nang, & Beilby, 2008) or word associations (Taylor, Lore, & Waldman, 1970) generated evidence that processes in semantic encoding operate along a similar time course in AWS versus TFA. In contrast, one investigation found that AWS produced word associations faster than TFA (Jensen, Markel, & Beverung, 1986). Another found that AWS were more variable than TFA in the time taken to produce word associations (Crowe & Kroll, 1991). Still another study found that AWS were slower than TFA in identifying category-specific words in sentence stimuli (Bosshardt & Fransen, 1996). On the basis of the mix of evidence outlined here, it remains unresolved whether semantic encoding operates along a similar time course in AWS versus TFA.

The time course of phonological encoding has also been investigated in AWS. Some experiments requiring explicit verbal responses in the context of phonological priming manipulations found no evidence of slowed phonological encoding in AWS (Burger & Wijnen, 1999; Hennessey et al., 2008). In contrast, other studies found a disproportionately larger word frequency effect on naming speed in AWS versus TFA (Newman & Bernstein Ratner, 2007; Prins, Main, & Wampler, 1997; although see Kami, Shine, & Rastatter, 2000). Even for TFA, lower-frequency words tend to elicit longer naming latencies than higher-frequency words. This word frequency effect on naming has been localized to the phonological encoding stage of word production (see Jescheniak & Levelt, 1994; Roelofs, 1997). That this effect was even larger in magnitude in AWS points to slower phonological encoding in this speaker group. Still other reports found evidence of slower phonological encoding in AWS when overt speech was not required, that is, in subvocalized phonological encoding tasks (Bosshardt & Nandyal, 1988; Hand & Haynes, 1983; Postma, Kolk, & Povel, 1990; Rastatter & Dell, 1987; Sasisekaran, De Nil, Smyth, & Johnson, 2006). There is evidence, too, that phonological encoding times slow disproportionately in AWS

as cognitive processing demands of phonological encoding increase (Jones, Fox, & Jacewicz, 2012; Weber-Fox, Spencer, Spruill, & Smith, 2004). On the basis of this mix of evidence, it is also unresolved whether phonological encoding operates along a similar time course in AWS versus TFA.

Beyond Behavioral Measurements of Language Production in AWS

Language production is a largely cognitive phenomenon involving different types of linguistic representations (i.e., lexical-semantic, syntactic, and phonological) stored and processed somewhat independently and are, thus, dissociable experimentally (Bock, 1996). As cited previously, a number of behavioral approaches have been used to investigate language production in AWS. Many of them relied on behavioral reaction time (RT) measures to gain insight into semantic and phonological encoding time course in AWS.

The approach of using RT measures to estimate the time course of specific language processes may be constrained when applied to AWS. In general, RT measures index the termination of a potentially complex stream of information-processing activities (Meyer, Osman, Irwin, & Yantis, 1988). Speech RTs, in particular, can "...reflect the combined influence of a large number of processes in both the linguistic and the motor domain" (Peters, Hulstijn, & Van Lieshout, 2000, p. 105). Speech RTs recorded in picture naming have been used successfully to estimate the time course of language production in TFA. However, this approach rests on the assumption that speech motor control is fairly stable in TFA and that specific experimental manipulations (e.g., priming contexts, distractor words) are primarily responsible for modulating naming RTs. In contrast, there is evidence that at least some AWS have slower and more variable vocal, oral, and manual RTs even in the absence of language-processing demands (see Bloodstein & Bernstein-Ratner, 2008). Thus, using speech RTs to draw inferences about the speed of language processing may be confounded by inefficient and less stable motor control in AWS. Also unknown is whether RT differences reflect physiological deficits versus response strategies possibly adopted by AWS to manage performance on experimental tasks (see Bakker & Brutton, 1989).

An alternative is to use ERPs to estimate the time course of processes in language production in AWS. Electrophysiological activity is generated by the brain as it is stimulated, both passively and while actively perceiving stimuli, making decisions, and regulating behavior. ERPs can be recorded at the scalp with temporal resolution on the order of milliseconds. Moreover, specific components of the ERP signal index specific cognitive processes. Thus, ERPs provide a noninvasive yet high-resolution means of estimating how quickly specific cognitive processes unfold in real time. To date, ERPs have been used to investigate cognitive processes in language production (Maxfield et al., 2010, 2012, 2015, 2016) and language comprehension (Murase, Kawashima, Satake, & Era, 2016; Weber-Fox & Hampton, 2008) in AWS. However, the precise temporal

resolution of ERPs has not yet been leveraged to investigate language production time course in AWS.

ERP Correlates of Semantic and Phonological Encoding Times

A number of existing research paradigms use ERPs to index the time course of language production (see Ganushchak, Christoffels, & Schiller, 2011). The first to be developed, and the one adopted here, involves investigating the time course of ERPs elicited as participants name and make lexical decisions about picture stimuli (e.g., van Turenout et al., 1997). In previous studies of this kind, TFA named pictures (explicitly or tacitly) and made dual-choice decisions about the animacy of pictured objects (semantic judgments) and also about the presence of specific phonemes in the target picture labels (phonemic judgments). In some conditions, semantics drove the choice of whether or not to respond by pressing a button (Go vs. NoGo), whereas the presence of target phonemes determined the response hand (left vs. right). In other conditions, the response mappings were reversed.

Two ERP components elicited by the dual-choice task have been targeted for time course measurement. These are the NoGo N200 component and the lateralized readiness potential (LRP). NoGo N200 is elicited to NoGo trials and is taken to index a decision by the prefrontal cortex to inhibit responding based on evaluation of a stimulus (Schmitt et al., 2000). One prediction of the dual-choice task, outlined previously, is that NoGo N200 activity should appear earlier in time (relative to picture onset) to semantic NoGo trials than to phonemic NoGo trials. This is based on the assumption that semantic information becomes available earlier than phonological information in language production and, thus, should trigger response inhibition along an earlier time course. This effect has been observed in TFA (Schmitt et al., 2000).

In contrast to the NoGo N200, LRP activity appears when stimulus information associated with a specific hand response activates response preparation (Kutas & Donchin, 1980). Crucially, LRP activity may be detected even when an overt motor response is not executed. This may occur, for example, when evaluation of a stimulus results in early retrieval of information associated with a specific hand response and cues the premotor cortex to begin preparing that response, after which other information associated with a NoGo decision is retrieved and cues the premotor cortex to stop preparing the response (Gratton, Coles, & Donchin, 1992; Smid, Mulder, Mulder, & Brands, 1992). Several researchers have attempted to capitalize on this property of the LRP to index the time course of semantic and phonological encoding in language production (e.g., Rahman & Sommer, 2003; Rodriguez-Fornells, Schmitt, Kutas, & Münte, 2002; Schmitt et al., 2000; van Turenout et al., 1997; Zhang, Damian, & Yang, 2007). Predictions relating to LRP activity, outlined next, once again assume that semantic information is processed earlier than phonological information in picture naming.

In the dual-choice context outlined previously, when the response hand (left vs. right) is driven by semantic judgments and Go/NoGo by phonemic judgments, LRP activity should begin to appear (based on the early availability of semantic information cuing a specific hand response). If the phonemic decision signals a Go response, then the LRP activity that was initially triggered by semantic evaluation of the picture should continue developing, steadily increasing in amplitude. On the other hand, if the phonemic decision signals NoGo, then the LRP activity initially triggered by semantic evaluation of the picture should stop developing and lose amplitude. Under these conditions, LRP onset on both Go and NoGo trials reflects the time at which semantic information becomes available to initiate response preparation, whereas the point at which NoGo LRPs diverge from Go LRPs reflects the time at which phonemic information becomes available to abolish response preparation. When instructions are reversed, such that the response hand (left vs. right) is driven by the phonemic decision and Go/NoGo by semantics, LRP is not expected to appear at all to semantic NoGo trials (based on early availability of semantic information signaling a NoGo decision before specific hand preparation can begin based on phonemics). These effects have been observed repeatedly in TFA (Schmitt et al., 2000; van Turenout et al., 1997).

The dual-choice paradigm was adopted here to compare the time course along which semantic and phonological information influences response inhibition (as indexed by NoGo N200 activity) and response preparation (as indexed by LRP activity) in AWS versus TFA. On each trial, participants made a dual-choice decision about semantic and phonological information associated with a picture. The semantic decision targeted animacy (whether or not the picture depicted a living vs. nonliving object), and the phonemic decision targeted whether one of two phonemes was present in the picture's label (/k/ vs. /l/). The lexical decisions were mapped onto the Go–NoGo/left–right response paradigm described previously. Instead of locating the target phonemes in a single word position (e.g., as in Schmitt et al., 2000; van Turenout et al., 1997), their location was varied relatively equally between word-initial, -medial, and -final positions. The locations of the target phonemes were varied in this manner to encourage access to the complete string of phonemes associated with each picture label, because overt naming was not required. Consistent with previous reports, earlier versus later NoGo N200 activity was predicted to semantic versus phonemic NoGo trials. NoGo N200 time course was also compared between groups. In addition, LRP latencies were measured to gain insight into the time course of semantic and phonological influences on response preparation in AWS versus TFA.

Method

Participants

The study was approved by the institutional review board at the University of South Florida's (USF) Tampa

campus. Initially, 20 AWS (six women, 14 men; mean age = 26 years 1 month) and 20 TFA (six women, 14 men; mean age = 24 years 9 months) were tested. However, as described later, 16 participants were ultimately included in each group in the reported analysis. AWS were recruited by advertising the study to a database of AWS gathered over years by the author, in addition to electronic advertisements in local newspapers and fliers posted on USF's Tampa campus. TFA were recruited by advertising the study in local newspapers and in e-mails sent by academic advisors to the student body at USF (excluding Communication Sciences and Disorders majors). Recruitment of TFA lagged recruitment of AWS in order to monitor matching of the groups on parameters of age, gender, handedness, and education.

Each participant gave written informed consent before testing and received \$50 upon completion. At time of testing, participants reported that they were in good health, had no history of neurological injury or disease, were not taking medications that affect cognitive functions, had normal or corrected-to-normal vision, had normal hearing, and had typical language abilities. TFA additionally had no history of speech difficulties. AWS had an established diagnosis of stuttering but no other speech difficulties. All participants were born in the United States, spoke English as their only language, and minimally had a high-school education. All participants scored within normal limits on the Peabody Picture Vocabulary Test–Fourth Edition, Form B (PPVT-4; Dunn & Dunn, 2007) and the Expressive Vocabulary Test–Second Edition, Form B (EVT-2; Williams, 2007). Anyone not meeting these criteria at time of testing was excluded.

The two groups were initially well matched by age, gender, handedness, and education. However, statistically significant differences were detected between groups in PPVT-4 and EVT-2 scores, with TFA having higher average scores than AWS on each measure. To address these differences, two men and two women with the highest PPVT-4 and EVT-2 scores were excluded from the TFA group. In addition, two men and two women with the lowest PPVT-4 and EVT-2 scores were excluded from the AWS group. No additional factors were considered when matching groups on vocabulary.

Included for analysis were 16 AWS (four women, 12 men; mean age = 25 years 8 months) and 16 TFA (four women, 12 men; mean age = 24 years 4 months). The difference in age in months was not statistically significant, $t(30) = 0.79$, $p = .44$. Two TFA (one woman, one man) and one AWS (female) self-reported that they were left-handed. Group did not affect PPVT-4 scores (TFA mean score = 108.69, $SD = 10.52$; AWS mean score = 106.81, $SD = 8.85$), $t(30) = 0.55$, $p = .59$, or EVT-2 scores (TFA mean score = 108.81, $SD = 8.18$; AWS mean score = 107.38, $SD = 10.39$), $t(30) = 0.44$, $p = .67$. Eight TFA had a high-school education, six had an earned undergraduate college degree, and two had an earned master's degree. Six AWS had a high-school education, two completed vocational technical school after high school, six had an earned undergraduate college degree, and two had an earned master's degree.

For AWS, the presence of stuttering was verified by the author using conversational samples digitally video-recorded from each participant. A 300-word speech sample, taken from the midpoint of a conversation with the author, was transcribed and coded for primary stuttering behaviors (specifically including audible sound prolongations, silent blocks, and sound/syllable repetitions) and secondary stuttering behaviors (specifically including gross motor, fine motor, breath stream/laryngeal, and verbal secondary behaviors). On the day of testing, 10 AWS stuttered on at least 5% of syllables, four AWS stuttered on at least 10% of syllables, and two AWS stuttered on at least 15% of syllables. Although these percentages have been associated with “mild,” “moderate,” and “severe” stuttering severities, respectively (Healey, 2010), stuttering frequency can have high day-to-day variability (Constantino, Leslie, Quesal, & Yaruss, 2016). Each AWS exhibited two or more secondary behaviors of stuttering. In addition to verifying the presence of stuttering, impacts of stuttering on quality of life were measured using the Overall Assessment of the Speaker's Experience With Stuttering (Yaruss & Quesal, 2006). Self-rated impact of stuttering was mild for one AWS, mild-moderate for seven AWS, and moderate for eight AWS.

Stimuli

Stimuli included 52 black line drawings from the International Picture Naming Project (Szekely et al., 2004). Half depicted common objects and the other half depicted animals. Each picture elicited a target noun label in English with 82% or better agreement according to International Picture Naming Project norms ($M = 0.94$ agreement, $SD = 0.06$). Half the target labels in each category contained the /l/ phoneme, and the other half contained the /k/ phoneme. The phoneme-bearing location was varied relatively equally between word-initial position ($n = 4$ animals began with /k/, $n = 5$ objects began with /k/, $n = 3$ animals began with /l/, $n = 3$ objects began with /l/), word-medial position ($n = 6$ animals with medial /k/, $n = 4$ objects with medial /k/, $n = 5$ animals with medial /l/, $n = 4$ objects with medial /l/), and word-final position ($n = 3$ animals ended with /k/, $n = 4$ objects ended with /k/, $n = 5$ animals ended with /l/, $n = 6$ objects ended with /l/). Target picture labels had a maximum of four syllables ($M = 1.78$ syllables, $SD = 0.8$) and eight phonemes ($M = 4.56$ phonemes, $SD = 1.57$).

Procedure

Participants were tested in a single session. First, they were familiarized with the picture stimuli, which were printed in a booklet along with the target label for each picture. After studying the booklet, participants were shown each picture on a computer screen and asked to name each aloud. The order was fully randomized. The session proceeded to the main experiment when 100% naming accuracy was achieved.

For the main experiment, participants were instructed to tacitly label and make two different judgments about

each picture. One judgment (semantic) was whether each picture was an animal or object, and the other judgment (phonemic) was whether the target label for each picture contained the /l/ or /k/ phoneme anywhere in the word. The judgments were mapped onto eight different sets of response instructions:

1. If animal then go, if /k/ go with left hand.
2. If animal then go, if /l/ go with left hand.
3. If object then go, if /k/ go with left hand.
4. If object then go, if /l/ go with left hand.
5. If /k/ then go, if animal go with left hand.
6. If /k/ then go, if object go with left hand.
7. If /l/ then go, if animal go with left hand.
8. If /l/ then go, if object go with left hand.

The experiment consisted of eight blocks of 52 trials. Each block featured one of the eight sets of response instructions. The main set of 52 pictures was presented in randomized order in each block. The order of response instructions was randomized.

Each trial consisted of a crosshair (+) shown in the middle of a computer screen for a randomly selected duration between 1,500 and 3,000 ms. The crosshair duration was varied to limit the influence of contingent negative variation activity on the prestimulus baseline interval of picture-locked ERPs (following Schmitt et al., 2000). Following the crosshair, a picture was shown for 1,500 ms. The time-out period for responding was 1,500 ms.

Before each block of trials, participants practiced responding to a set of 24 practice stimuli ($n = 6$ animals containing /l/, $n = 6$ animals containing /k/, $n = 6$ objects containing /l/, $n = 6$ objects containing /k/). Each main experimental block began when the participant achieved 100% accuracy on the practice items. A break lasting 10–15 min was provided between blocks.

Recording and Apparatus

Each participant sat in a sound-attenuating booth facing a 19-in. monitor. Maximum onscreen height and width of the pictures measured 10.7 cm. Viewing distance was ~90 cm. The visual angle of the pictures subtended ~6.8°. The E-Prime software (Psychological Software Tools, Version 1.1) controlled the experiment. A response box registered push-button RTs. Accuracy was scored online by E-Prime.

Each participant wore a nylon QuikCap (Neuroscan) fitted with 32 active recording electrodes positioned following the International 10–20 system (Klem, Lüders, Jasper, & Elger, 1999). Active recording electrodes were referenced to a midline vertex electrode. A ground electrode was positioned on the midline, anterior to Fz. Two bipolar-referenced vertical electro-oculograph electrodes and two bipolar-referenced horizontal electro-oculograph electrodes recorded electro-ocular activity. Electrodes were constructed of Ag/AgCl.

An electroencephalograph (EEG) was recorded continuously at a sampling rate of 500 Hz, controlled using SCAN software, Version 4.3 (Neuroscan). Electrode impedance was 5 k Ω or less. Continuous EEG data were low-pass filtered online at a corner frequency of 100 Hz (time constant: DC).

EEG-to-ERP Reduction

The continuous EEG record of each participant for the task was segmented into epochs. Each epoch comprised EEG data recorded from each electrode during presentation of the picture on each trial, beginning 300 ms before and terminating 1,700 ms after picture onset. Similar to the procedure used by Schmitt et al. (2000), the first seven items in each block were treated as warm-up trials and discarded. Trials eliciting incorrect judgments were also excluded. To retain as many trials as possible (Picton et al., 2000), an independent component analysis-based (Bell & Sejnowski, 1995) ocular artifact correction procedure (Glass et al., 2004) was implemented in MATLAB. After independent component analysis blink correction, channels with fast average amplitude exceeding 200 μ V (large drift) were marked bad, as were channels with differential amplitude exceeding 100 μ V (high-frequency noise). Any EEG trial with more than three bad channels was rejected. For any accepted trial with channels marked bad, the EEG activity at those channels was replaced using a three-dimensional spline interpolation procedure implemented in MATLAB (Nunez & Srinivasan, 2006, Appendices J1–J3). Accepted EEG trials were then averaged together, separately for each condition.

For the NoGo N200 analysis, no fewer than 70 artifact-free trials went into the set of ERP averages for each participant in each of four conditions: semantic judgment signals a Go response (TFA $M = 94.88$ trials, $SD = 8.49$; AWS $M = 94.25$ trials, $SD = 5.26$), semantic signals NoGo (TFA $M = 99.25$ trials, $SD = 7$; AWS $M = 101.56$ trials, $SD = 3.16$), phonemic judgment signals Go (TFA $M = 94.44$ trials, $SD = 5.46$; AWS $M = 93.13$ trials, $SD = 6.05$), and phonemic signals NoGo (TFA $M = 100.56$ trials, $SD = 4.19$; AWS $M = 101.69$ trials, $SD = 2.02$). As these numbers show, the mean number of trials included for averaging per condition for the NoGo N200 analysis was comparable between groups. Go ERP averages tended to be composed of a mean of ~6 fewer trials than NoGo ERP averages for each group in each linguistic condition.

For the LRP analysis, no fewer than 34 artifact-free trials went into the set of ERP averages for each participant in each of the eight instruction sets: semantic judgment signals a Go response and phonemic judgment signals the right hand (TFA $M = 47.56$ trials, $SD = 4.03$; AWS $M = 47.19$ trials, $SD = 2.56$), semantic judgment signals Go and phonemic judgment signals the left hand (TFA $M = 47.31$ trials, $SD = 4.77$; AWS $M = 47.06$ trials, $SD = 3.15$), semantic judgment signals NoGo even though phonemic judgment signals the right hand (TFA $M = 49.94$ trials, $SD = 3.02$; AWS $M = 50.69$ trials, $SD = 2.18$), semantic judgment signals NoGo even though phonemic judgment

signals the left hand (TFA $M = 49.31$ trials, $SD = 4.17$; AWS $M = 50.88$ trials, $SD = 1.2$), phonemic judgment signals a Go response and semantic judgment signals the right hand (TFA $M = 47.25$ trials, $SD = 2.65$; AWS $M = 46.25$ trials, $SD = 3.13$), phonemic judgment signals Go and phonemic judgment signals the left hand (TFA $M = 47.19$ trials, $SD = 3.25$; AWS $M = 46.88$ trials, $SD = 3.46$), phonemic judgment signals NoGo even though semantic judgment signals the right hand (TFA $M = 50.63$ trials, $SD = 1.63$; AWS $M = 51.06$ trials, $SD = 1$), and phonemic judgment signals NoGo even though semantic judgment signals the left hand (TFA $M = 49.94$ trials, $SD = 2.81$; AWS $M = 50.63$ trials, $SD = 1.45$). As these numbers show, the mean number of trials included for averaging per condition for the LRP analysis was comparable between groups, and NoGo averages were composed of a few more trials than Go averages in each group.

For both the NoGo N200 and LRP analysis, the averaged ERP data were re-referenced to averaged mastoids, truncated to the critical time window (-100 to $1,500$ ms), and finally baseline-corrected (-100 to 0 ms). The NoGo N200 and LRP analyses described below were carried out on these unfiltered averages. The ERP averages were low-pass filtered at a corner frequency of 40 Hz for graphing purposes only.

Analysis

Behavioral Data

As noted previously, the first seven items in each block were treated as warm-up trials and discarded. Behavioral data for the remaining trials were analyzed as follows. Response accuracy was averaged across the left and right hands, separately for each subject, in each of four conditions (semantic judgments signaling a Go response, semantic judgments signaling NoGo, phonemic judgments signaling Go, phonemic judgments signaling NoGo). Accuracy scores were submitted to a repeated-measures analysis of variance (ANOVA) with linguistic condition as a within-subject factor with two levels (semantic, phonemic), response condition as a within-subject factor with two levels (Go, NoGo), and group as a between-subjects factor with two levels (AWS, TFA). Push-button RTs on correct trials were averaged across the left and right hands, separately for each subject, in each of two conditions (semantic judgments signaling Go, phonemic judgments signaling Go) and submitted to a repeated-measures ANOVA with linguistic condition as a within-subject factor with two levels (semantic, phonemic) and group as a between-subjects factor with two levels (AWS, TFA). Both ANOVAs had an alpha level of .05. Statistically significant interactions were followed up with Bonferroni-corrected pairwise comparisons.

NoGo N200 Analysis

NoGo N200 typically has a frontally focused scalp topography. To isolate this effect, difference waves (NoGo minus Go) were computed at electrodes FP1 and FP2. The difference waves were then quantified using a point-by-

point amplitude computation. Specifically, difference wave amplitudes were measured, once every 2 ms beginning at 100 ms and ending at 600 ms after picture onset (the time range in which NoGo N200 typically appears), by computing the average amplitude across a 40 -ms window centered around each time point (± 20 ms). Serial t tests (one-sided) determined the time point(s) at which difference wave amplitudes showed a significant divergence from zero. Significant divergence from zero was defined as the point at which eight consecutive t tests showed a statistically significant difference from zero. Paired-samples t tests (two-sided) compared semantic versus phonemic difference wave amplitudes over time separately for each group at each electrode. Finally, independent-samples t tests (two-sided) compared difference wave amplitudes over time between groups in each linguistic condition at each electrode. This same analysis approach was used by Schmitt et al. (2000) and is recommended in international publication guidelines for quantifying the onset and duration of ERP components (Picton et al., 2000).

LRP Analysis

LRPs were derived for each participant in each of four conditions: semantic judgments signaling a Go response, semantic judgments signaling NoGo, phonemic judgments signaling Go, and phonemic judgments signaling NoGo. For each subject in each condition, LRPs were computed by subtracting ERPs recorded over the left motor region on the scalp (Electrode C3) from ERPs recorded over the right motor region (Electrode C4). This subtraction was completed for trials on which the left hand was correct and, separately, for trials on which the right hand was correct. The two difference waves were then averaged (Coles, Gratton, & Donchin, 1988). The computed LRPs reflect activity specifically related to preparing a cued hand to move (Kutas & Donchin, 1974, 1980).

LRPs were measured using the point-by-point amplitude computation described previously for the N200 analysis. First, LRP amplitudes were computed, once every 2 ms beginning at 100 ms and ending at $1,400$ ms after picture onset (the time range in which LRP activity would be expected to occur), by computing the average amplitude across a 40 -ms window centered around each time point (± 20 ms). One-sided serial t tests determined the time point(s) at which LRP amplitudes showed a significant divergence from zero. Once again, significant divergence from zero was defined as the point at which eight consecutive t tests showed a statistically significant difference from zero. Paired-samples t tests (two-sided) compared LRP amplitudes over time between linguistic conditions, separately for each group in each response condition. Independent-samples t tests (two-sided) compared LRP amplitudes over time between groups, separately for each linguistic condition in each response condition. This same analysis approach was also used by Schmitt et al. (2000) and van Turenhout et al. (1997) to quantify the onset and duration of LRP activity to pictures.

Results

Behavioral Data

Response Accuracy

Response accuracy was affected by response condition, $F(1,30) = 79.01$, $p < .001$, with NoGo accuracy better than Go accuracy. As shown in Table 1, this pattern of results was present for each group in each linguistic condition. Response accuracy was not affected by main effects of linguistic condition or group. Nor was accuracy affected by the interaction of any factors.

Push-Button RT

Push-button RTs were affected by linguistic condition, $F(1,30) = 42.48$, $p < .001$, with faster RTs to semantic Go judgments than to phonemic Go judgments. As shown in Table 1, this pattern of results was present for each group. Push-button RTs were not affected by a main effect of group. Nor were RTs affected by an interaction of group and linguistic condition.

NoGo N200 Analysis

Grand-averaged waveforms to semantic Go versus NoGo trials and, separately, to phonemic Go versus NoGo trials are shown topographically for TFA (Figures 1 and 2) and AWS (Figures 3 and 4). For both groups, the averages are defined by early visual-evoked potentials followed by later activity. Crucially, ERPs to NoGo versus Go trials differ systematically, including at frontal electrodes where activity to NoGo trials was negative-going relative to Go trials, consistent with NoGo N200 component activity.

Grand-averaged difference waves (NoGo minus Go) at frontal electrodes (Figure 5) show that semantic NoGo N200 appeared earlier than phonemic NoGo N200 in both groups. This was verified by point-by-point amplitude analysis. In the TFA, semantic NoGo N200 deviated from zero ($p < .05$) between 130 and 414 ms at FP1 and between 120 and 392 ms at FP2. Phonemic NoGo N200 deviated from zero ($p < .05$) between 426 and 524 ms at FP1 and between 348 and 544 ms at FP2. Finally, semantic versus phonemic NoGo N200 differed in amplitude ($p < .05$)

between 188 and 344 ms at FP1 and between 184 and 340 ms at FP2.

In the AWS, semantic NoGo N200 deviated from zero ($p < .05$) between 196 and 402 ms at FP1 and between 228 and 414 ms at FP2. Phonemic NoGo N200 deviated from zero ($p < .05$) between 402 and 548 ms at FP1 and between 348 and 584 ms at FP2. Finally, semantic versus phonemic NoGo N200 differed in amplitude ($p < .05$) at FP1 between 216 and 266 ms. At FP2, semantic versus phonemic NoGo N200 activity was not found to differ in amplitude between 100 and 600 ms ($p > .05$).

Noteworthy is the markedly later semantic NoGo N200 onset for AWS versus TFA. At FP1, semantic NoGo N200 differed in amplitude ($p < .05$) in TFA versus AWS between 156 and 178 ms at FP1 and between 140 and 198 ms at FP2. In contrast, phonemic NoGo N200 did not differ in amplitude between groups at either electrode ($p > .05$).

LRP Analysis

Grand-averaged LRPs are shown in Figure 6. In the TFA, phonemic Go LRPs (trials on which semantics drove hand selection) deviated from zero ($p < .05$) beginning at 372 ms and continuing to 1,400 ms after picture onset. Semantic Go LRPs (trials on which phonemics drove hand selection) deviated from zero ($p < .05$) beginning at 418 ms through 882 ms after picture onset and then again between 1,082 and 1,400 ms. Semantic Go LRPs differed in amplitude from phonemic Go LRPs ($p < .05$) between 796 and 1,058 ms, with phonemic Go LRPs more negative than semantic Go LRPs.

In the AWS, phonemic Go LRP onsets deviated from zero ($p < .05$) beginning at 518 ms and continuing to 1,400 ms after picture onset. Semantic Go LRPs deviated from zero ($p < .05$) beginning at 496 ms and continuing to 1,400 ms after picture onset. Semantic Go LRPs were not found to differ in amplitude from phonemic Go LRPs ($p > .05$) at any latency in the AWS group.

Despite markedly later detectable Go LRP onsets between groups in each linguistic condition, Go LRP amplitudes were not found to differ between groups ($p > .05$)

Table 1. Push-button RT and percent accuracy for each group, in each linguistic condition, for each response condition.

Group	Linguistic × Response Condition	Mean RT (ms)	SD	Mean accuracy (%)	SD
AWS	Semantic Go	934.68	71.16	92.17	4.33
	Semantic NoGo	—	—	99.36	0.92
	Phonemic Go	981.92	95.59	91.00	4.88
	Phonemic NoGo	—	—	98.74	1.23
TFA	Semantic Go	895.74	107.03	95.28	5.14
	Semantic NoGo	—	—	98.77	1.71
	Phonemic Go	962.64	73.34	93.57	4.65
	Phonemic NoGo	—	—	99.66	0.66

Note. RT = reaction time; AWS = adults who stutter; TFA = typically fluent adults.

Figure 1. Grand-averaged waveforms for the typically fluent adults group to semantic Go trials (black) versus semantic NoGo trials (light gray) at each of 14 electrodes. Arrows point to NoGo N200 activity at FP1 and FP2.

with one exception. Sporadic amplitude differences were detected between groups for semantic Go LRP's relatively late, with greater negative-going activity for AWS versus TFA between 810 and 1,092 after picture onset ($p < .05$).

Finally, NoGo LRP activity was not detected for either group on trials wherein semantic judgments determined hand selection and phonemic judgments determined a NoGo decision, even though NoGo activity was expected for this condition (see Introduction). NoGo LRP activity was detected in both groups, albeit very late (see Figure 6), on trials wherein phonemic judgments determined hand selection whereas semantic judgments determined the Go/NoGo decision. Specifically, in the TFA, semantic NoGo LRP activity was detected intermittently ($p < .05$) between 1,058 and 1,160 ms after picture onset. In the AWS, semantic

NoGo LRP activity was detected continuously ($p < .05$) between 840 and 1,400 ms after picture onset.

Discussion

The study aim was to compare the time course of semantic and phonological encoding in picture naming in AWS versus TFA using a brain electrophysiological approach. On each trial, participants made a semantic judgment about a picture in addition to a phonemic judgment about the target picture label. Judgments were mapped onto a dual-choice (Go–NoGo/left–right) push-button response paradigm. NoGo ERPs were expected to diverge from Go ERPs at frontal electrodes, consistent with a NoGo N200 ERP component indexing response inhibition.

Figure 2. Grand-averaged waveforms for the typically fluent adults group to phonemic Go trials (black) versus phonemic NoGo trials (light gray) at each of 14 electrodes. Arrows point to NoGo N200 activity at FP1 and FP2.

Furthermore, NoGo N200 was predicted to appear earlier to semantic NoGo trials than to phonemic NoGo trials. This was observed in both groups. Moreover, semantic NoGo N200 had an earlier onset in TFA versus AWS, indicating that semantic encoding influenced response inhibition earlier in TFA versus AWS. Possible factors in slowed semantic encoding in AWS are considered. LRP activity, indexing response preparation, was also analyzed. LRP results, specifically for NoGo trials, were not as predicted.

Behavioral Findings

Accuracy of responding was affected by response condition, whereas speed of responding was affected by

linguistic condition. Between response conditions, Go trials elicited more errors than NoGo trials. Overall, error rates were relatively low in both groups and in all conditions despite the challenging nature of the dual-choice task.

Between linguistic conditions, semantic Go RTs were faster than phonemic Go RTs. RTs reported by Schmitt et al. (2000) for TFA in a similar task trended in this same direction. The significance of this pattern in relation to semantic versus phonological encoding times is not straightforward given that two decisions drove push-button responses on Go trials (i.e., a decision to Go and a decision about which hand to use). Between groups, AWS tended toward slower push-button RTs than TFA,

Figure 3. Grand-averaged waveforms for the adults who stutter group to semantic Go trials (black) versus semantic NoGo trials (light gray) at each of 14 electrodes. Arrows point to NoGo N200 activity at FP1 and FP2.

particularly to semantic Go trials, but the differences were not statistically significant.

NoGo N200 Effects

As in previous studies (see Ganushchak et al., 2011), NoGo ERPs diverged from Go ERPs at frontal electrodes, consistent with a NoGo N200 effect. Semantic NoGo N200 was earlier than phonemic NoGo N200. This pattern, present for both groups, aligns with previous evidence that semantic encoding generally begins before phonological encoding in language production (Levelt et al., 1999), thus influencing inhibitory control earlier.

Crucially, semantic NoGo N200 activity was detected earlier in TFA versus AWS. This difference was most pronounced at the right anterior scalp region, where NoGo N200 tends to be most robust, possibly due to generators in the right orbitofrontal cortex (Bokura, Yamaguchi, & Kobayashi, 2001). Semantic NoGo N200 began as early as 120 ms after picture onset in TFA. One of the first studies comparing NoGo versus Go ERPs in a semantic decision task found that ERPs in the two conditions diverged by ~150 ms after picture onset in TFA (Thorpe, Fize, & Marlot, 1996). Complex photographic stimuli were used in that study. There have since been reports that semantic processing of line drawings (as used here) can begin as early as 100 ms after picture onset (Hauk et al., 2007; Johnson &

Figure 4. Grand-averaged waveforms for the adults who stutter group to phonemic Go trials (black) versus phonemic NoGo trials (light gray) at each of 14 electrodes. Arrows point to NoGo N200 activity at FP1 and FP2.

Olshausen, 2005; Kirchner & Thorpe, 2006; Liu, Agam, Madsen, & Kreiman, 2009; Van Rullen & Thorpe, 2002). Thus, the current semantic NoGo N200 time course results for TFA are consistent with previous research.

Earlier semantic NoGo N200 activity in TFA versus AWS indicates that target semantic information became available to trigger response inhibition along a slower time course in AWS. Semantic NoGo N200 was detected 66 ms later in AWS versus TFA at electrode FP1 and 108 ms later in AWS versus TFA at electrode FP2. Furthermore, comparison of semantic NoGo N200 amplitudes between groups detected an onset difference at electrodes FP1 and FP2. As noted in the Introduction, AWS in a previous study were slower than TFA in identifying category-specific

words in sentence stimuli (Bosshardt & Fransen, 1996). More recently, ERPs in a sentence-processing task were found to modulate later in time to semantic violations in AWS versus TFA (Murase et al., 2016). These effects, too, point to slower speed of semantic processing in AWS.

On the other hand, differences were not detected between groups in the time course of phonemic NoGo N200 activity. This suggests that phonological information became available to trigger response inhibition along a similar time course in AWS versus TFA, in contrast to some other research findings outlined in the Introduction. It is noteworthy that phonemic NoGo N200 onsets at electrode FP2 were only slightly later for both groups in this study than in TFA tested in Schmitt et al. (2000). Thus, the current

Figure 5. Grand-averaged difference waves at frontal electrodes (FP1 and FP2), plotted separately for each group in each linguistic condition (semantic vs. phonological). Latencies on each graph give the first time point (in ms) at which N200 was detected. AWS = adults who stutter; TFA = typically fluent adults.

phonemic NoGo N200 time course results for both groups are consistent with previous findings. As discussed next, although the current NoGo N200 time course results generally replicated previously published research (with the exception of delayed semantic NoGo N200 onsets in the AWS), predicted NoGo LRP effects were not observed in either group.

LRP Findings

Go LRPs were readily detectable in each group for both semantic and phonemic Go conditions. Comparison of semantic versus phonemic Go LRP amplitudes, within groups, revealed no differences between linguistic conditions in TFA or in AWS, consistent with previous work of this type (e.g., Schmitt et al., 2000). AWS had later detectable LRP onsets than TFA on both semantic and phonemic Go trials. However, Go LRP amplitude differences were not detected, between groups, for phonemic Go LRPs. Semantic Go LRPs did differ in amplitude sporadically, between groups, beginning at ~800 ms after picture onset, indicative of very late differences in response preparation activity on semantic Go trials between groups.

Of critical importance, NoGo LRP results did not replicate those reported in previous studies (e.g., Schmitt et al., 2000; van Turenhout et al., 1997). It was predicted that LRP activity would develop initially and then attenuate to

phonemic NoGo trials. Conversely, LRP was not predicted to develop at all for semantic NoGo trials (see rationale in the Introduction). These patterns were not observed. Instead, LRP activity to phonemic NoGo trials went undetected in both groups. It is important to note that this predicted NoGo LRP effect was also unsuccessfully obtained in three other published language-processing studies with TFA (see Rahman & Sommer, 2003; Rodriguez-Fornells et al., 2002; Zhang et al., 2007). Furthermore, in the current task, LRP activity was detected to semantic NoGo trials fairly late following picture onset in both groups.

Borrowing an interpretation from Zhang et al. (2007), there is one possible reason why predicted phonemic NoGo LRP activity was not obtained. Namely, the decision not to produce a push-button response (based on the phonemic judgments) must have been used to prevent motor response preparation well before preparation of a specific response hand could begin (based on the semantic judgments). This would suggest that although semantic information became available before phonological information in both groups (according to the NoGo N200 time course results), semantic and phonological information influenced response preparation along a more parallel time course in the current task. The NoGo N200 and LRP components index different cognitive processes (i.e., inhibitory control vs. response preparation) and are presumed to have different underlying neural sources (i.e., prefrontal cortex for NoGo

Figure 6. Grand-averaged lateralized readiness potentials (LRPs) shown separately for each group in each response condition (left column = phonemic judgments drove Go/NoGo decisions; right column = semantic judgments drove Go/NoGo decisions). LRP were derived as described in the Method section. Latencies on each graph give the first time point (in ms) at which LRP activity was detected (if at all). AWS = adults who stutter; TFA = typically fluent adults.

N200 and premotor cortex for LRP; Schmitt et al., 2000; Zhang et al., 2007). Thus, it is not surprising that semantic and phonological information might influence these components along a different time course.

It has long been known that participants can exert strategic control over response preparation (for a review, see Coles, Smid, Scheffers, & Otten, 1995). In the current task, participants in both groups appear to have strategically prioritized the phonemic judgments in preparing hand movements. Two results support this conclusion. First, phoneme NoGo LRP activity went undetected in both groups, suggesting that phoneme NoGo decisions were made before semantic information cued response preparation for a specific hand on at least some trials. Second, late semantic NoGo LRP activity was detected in both groups. This suggests that, on at least some trials, a specific hand was selected based on phonemic information, activating LRP activity, which was later abolished by a NoGo decision based on semantics. As noted previously, the phonemic judgment task used here was quite different from those used in previous research. Perhaps a strategy of prioritizing the phonemic judgments in preparing hand responses helped optimize task performance in both groups.

Given that the predicted phonemic NoGo LRP effect was not obtained for either group in this study, the current LRP data cannot be used to estimate the real-time availability of semantic versus phonological encoding in either group. On the other hand, as discussed previously, semantic and

phonemic NoGo N200 time course results for TFA in this study and phonemic NoGo N200 time course results for AWS in this study were comparable to NoGo N200 time course results obtained from TFA in similar conditions in Schmitt et al. (2000). Because they replicate previous findings and are consistent with our current understanding of the time course of language production (i.e., that semantic encoding generally precedes phonological encoding), NoGo N200 results in these conditions seem to speak rather clearly to the central research issue, namely the real-time availability of semantic and phonological information in picture naming in AWS versus TFA. Next, possible factors in slowed semantic encoding in AWS are considered.

Possible Contributing Factors in Slowed Semantic Encoding in AWS

NoGo N200 activity indicated that target semantic information became available to trigger response inhibition more slowly in AWS versus TFA. Here, speculation is raised about possible factors contributing to slowed semantic encoding in AWS. First, there is evidence that orienting attention, which mediates the selection of information from sensory input (Petersen & Posner, 2012), operates poorly in children who stutter versus typically fluent children (Eggers, De Nil, & Van den Bergh, 2009). There is also evidence that children who stutter organize or process words within a less mature semantic framework (Hartfield

& Conture, 2006). One possibility is that these differences persist into adulthood, with AWS requiring more time to orient attention to and/or consolidate relevant semantic information in picture naming.

Even if orienting attention and lexical abilities were to develop normally in children who stutter (see Nippold, 2012), experience over time with stuttering might still come to impact speed of semantic processing in AWS. Behaviorally, adulthood stuttering may be characterized by primary symptoms and secondary behaviors (Wingate, 1964) as operationalized in the Method section. Verbal accessories (e.g., word substitutions, circumlocutions, starters, retrials, and stall tactics) are among the most common secondary behaviors used by AWS to escape from, or avoid, stuttering (Rochford, 1983; Vanryckeghem, Brutten, Uddin, & Van Borsel, 2004). Maxfield et al. (2010) found evidence that semantic neighbors of target words gain disproportionate activation strength in AWS on the path to naming and questioned whether this was a by-product of habitual word substitution behavior. By heightening competition among semantically related words, habitual word substitution behavior might also prolong the time needed to resolve competition among semantically related words in picture naming, providing a second possible route through which slowed semantic encoding might come about in AWS. Additional research is needed to determine whether the factors mentioned here, and any others,^{1,2} influence speed of semantic

¹For example, a model of speech production published very recently claims that lexical retrieval is driven, in part, by a lexical-auditory feedback stream (Walker & Hickok, 2016). According to this model, talkers make reference to auditory targets for sounds and words formed during language acquisition in childhood. Those lexical-auditory targets, in turn, play a role in driving which words are activated on the path to speech production. There is evidence that decrements in auditory processing are associated with adulthood stuttering (e.g., Daliri & Max, 2015). Thus, a third possibility is that slowed semantic encoding in AWS may be a by-product of atypical lexical-auditory feedback connections.

²Another consideration is whether slowed semantic NoGo N200 onset in AWS was a by-product of strategic emphasis on mapping phonemic judgments onto specific hand movements. Previous evidence suggests that AWS may withdraw resources from semantic processing to manage other task demands (Bosshardt, 2006). In the current task, perhaps delaying onset of semantic processing helped AWS efficiently map phonemic decisions onto specific hand movements. On the other hand, there are neurophysiological reasons to suspect that delayed semantic NoGo N200 activation in AWS was not the result of a strategic shift away from semantic processing to manage response preparation. Fuster (2001) proposed a timeline of information processing in which sensory information leads to motor action. According to this timeline, information retrieved from the environment (e.g., from picture stimuli) is first evaluated by the prefrontal cortex. Schmitt et al. (2000) assumed that this stage of evaluation is indexed by NoGo N200 activity. Once evaluated, the information is then transmitted to the motor cortex (Fuster, 2001), reflected in LRP activity (Schmitt et al., 2000). Based on this timeline, delayed semantic NoGo N200 onsets in AWS could not have been a by-product of strategic emphasis on response preparation based on the phonemic judgments, because information processing indexed by NoGo N200 always precedes information processing indexed by LRP.

encoding in AWS. Whatever the basis, a critical question is how might slowed semantic encoding produce stuttering.

How Might Slowed Semantic Encoding Affect Fluency in AWS?

The covert repair hypothesis (Postma & Kolk, 1993) provides a starting point for speculating about how slowed semantic encoding might produce stuttering-like disfluencies. This hypothesis assumes that language production operates under time constraints, during which specific types of linguistic information (e.g., semantic, lexical, and phonological) must gain activation strength. Linguistic representations most strongly activated within a limited time window are selected to be included in the linguistic plan for the intended utterance. Crucially, slowed processing can result in erroneous selection of linguistic information. Furthermore, erroneously selected linguistic information can be detected by an internal error monitor, which, in turn, may interrupt speech and initiate a repair, interrupting fluency in the process.

Speech repair happens in three phases: (a) error detection and interruption; (b) hesitation, pausing, or use of editing terms; and (c) initiation of a repair proper (Levelt, 1983). Postma and Kolk (1993) focused on the nature of the repair proper (phase three) in connecting speech repair to stuttering. In their hypothesis, semantic, lexical, and phonological errors can be detected by internal monitoring and trigger a repair. Of critical importance, the authors assumed that the nature of the repair following each error type differs. Specifically, they proposed that semantic errors result in phrase repetitions or long silent pauses, that lexical errors result in word repetitions or silent pauses, and that phonological errors result in intrasyllabic disfluencies (e.g., blocking, prolongation, and sound/syllable repetition). Based in part on these proposed repair types, Postma and Kolk hypothesized that phonological encoding is slowed in AWS, resulting in phonological errors that are detected by internal monitoring, which may then trigger intrasyllabic repairs having characteristics of stuttering-like disfluencies.

The current NoGo N200 results pointed to slower speed of semantic encoding in AWS versus TFA, whereas no differences in phonological encoding time course were found between groups. Slowed semantic encoding might result in semantic errors (e.g., message formulation or semantic appropriateness errors). Slowed semantic encoding might also result in lexical selection errors (e.g., by slowing the activation of words associated with specific concepts, potentially allowing nontarget words to be selected). Furthermore, as noted previously, semantic and lexical errors might get detected by internal monitoring. Beyond this point, the covert repair hypothesis would not explain how stuttering-like disfluencies might come about from slowed semantic encoding (i.e., none of the repair types potentially resulting from covert detection of semantic or lexical errors, noted previously, resemble stuttering). However, other phases of speech repair—not emphasized in the covert repair hypothesis—potentially do give rise to disfluencies resembling

stuttering, even when semantic or lexical errors are involved.

In an analysis of speech error data, Levelt (1983) observed that TFA sometimes produce within-word interruptions. He used this observation to propose that when linguistic formulation errors are detected by internal monitoring, speech interruption (Phase 1 of speech repair) can occur immediately without regard to word or phrase boundaries, after which a repair may be initiated. Further analysis showed that within-word interruptions are more likely to occur when an erroneous word is selected (Levelt, 1984). That speech can be interrupted immediately anywhere in the speech stream upon error detection—including before articulation of a word is initiated (Nooteboom, 1980)—raises the possibility that stuttering-like disfluencies might at least begin as immediate interruptions triggered by semantic or lexical errors detected covertly.³

Some would correctly point out that the speech of AWS is not typically characterized by an unusually high frequency of frank semantic or lexical errors (although AWS may make more naming errors in experimental settings; e.g., Newman & Bernstein Ratner, 2007) and that stuttering-like disfluencies tend to affect intended words in AWS. Still, it seems reasonable to consider whether internal monitoring might trigger immediate/within-word interruptions upon detecting slow (if not erroneous) semantic encoding activity in AWS. Similarly, might internal monitoring trigger immediate/within-word interruptions upon detecting difficult (if not erroneous) lexical selection in AWS? With regard to the latter, some of my previous research findings suggest that AWS heighten attentional control in lexical selection, pointing to difficulty in this process (Maxfield et al., 2010, 2015, 2016). The idea that internal monitoring may be hypersensitive to inefficient linguistic processing in AWS is not new (Vasic & Wijnen, 2005). Whether internal monitoring detects slowed semantic encoding and/or difficult lexical selection in AWS and whether immediate/within-word interruptions

are triggered in such instances in AWS are questions for future research. There may also be other routes from slowed semantic encoding to stuttering-like disfluencies.^{4,5}

Study Limitations

The research design used here was originally developed because it engages processes in semantic and phonological encoding while reducing speech movement artifact. However, the design is not without limitations. As pointed out by Ganushchak et al. (2011), tacit naming may attenuate some processes that would usually be active in language production. Bolstering this point, recent evidence suggests that intention-to-speak facilitates lexical access in overt picture naming (Strijkers, Holcomb, & Costa, 2011). In addition, the task is heavily reliant on metalinguistic ability. Moreover, tacit naming makes it difficult to verify that participants follow instructions. Unknown is how these factors may have impacted current findings.

Another possible limitation, also related to task design, concerns the phonemic judgments. As discussed previously, the phonemic judgments used here differed from those used in previous dual-choice lexical decision studies. This seems to have affected the LRP results, although this was useful in revealing a dissociation between language-processing influences on response inhibition versus response preparation. As mentioned in Footnote 2, there are neurophysiological reasons to suspect that strategically emphasizing phonemic judgments in preparing specific hand responses did not influence the NoGo N200 results. Still, it might be informative to repeat this study using a simpler phonemic judgment task requiring participants to determine whether specific phonemes are present at a fixed word location.

Finally, the sampling procedure might be called into question. As described in the Method section, 20% of participants were excluded, after testing, in order to match the groups on measures of receptive and expressive vocabulary knowledge. On the one hand, international publication guidelines for ERP studies require that control subjects be chosen so that they differ from experimental subjects only on the parameter being investigated to the extent possible (Picton et al., 2000). On the other hand, a reduced sample size may have some bearing on what can be generalized from the results, particularly in removing AWS with low normal vocabulary knowledge. With that said, it is worth noting that an analysis including all 20 participants in each group (not reported) produced largely identical results, particularly in the N200 time course analysis.

³Levelt (1983) also found that within-word interruptions to covert error detection are not mandatory. That is, TFA often continue producing speech beyond covertly detected errors (e.g., until they reach a phrase boundary), called delayed interruptions (Blackmer & Mitton, 1991), apparently to minimize disruptive effects of interruption and repair on fluency (Seyfeddinipur, Kita, & Indefrey, 2008; Tydgate, Stevens, Hartsuiker, & Pickering, 2011). Citing delayed interruptions, Postma and Kolk (1993) downplayed the possibility that covert error detection could disproportionately result in immediate (e.g., within-word) interruptions in AWS. However, recent evidence suggests that speech monitoring operates in a hypervigilant manner in AWS (Arnstein, Lakey, Compton, & Kleinow, 2011), which seems inconsistent with a preference for delayed interruptions to covert error detection. Furthermore, delayed interruptions often proceed in parallel with formulation of a repair (Hartsuiker & Kolk, 2001), and it is not clear whether AWS possess the attentional capacity to continue producing speech beyond a covertly detected error while simultaneously formulating a repair proper (see Bajaj, 2007; Bosshardt, 2006; Maxfield et al., 2016). An alternative possibility is that linguistic formulation errors (e.g., semantic or lexical errors) interrupt speech immediately in AWS, as they sometimes do in TFA, perhaps more frequently in AWS.

⁴For example, it may be useful to revisit the EXPLAN theory of stuttering (Howell, 2004) from the perspective of slowed semantic encoding in AWS.

⁵It also seems important to acknowledge that speech is planned and articulated in overlapping increments (Kempen & Hoenkamp, 1987). From this perspective, still another question is whether slowed semantic encoding for a forthcoming increment might impact articulation of an already-planned/ready-to-be-articulated increment.

Summary and Conclusions

Dual-task lexical decision accuracy and speed were similar in AWS and TFA at a behavioral level. However, frontal ERP activity indexing inhibitory control (NoGo N200 component) was influenced by semantic decisions significantly later in AWS versus TFA. This finding indicates that semantic information triggered response inhibition more slowly in AWS versus TFA in the current experiment. In contrast, phonological information triggered response inhibition along a similar time course between groups.

Other ERP activity, related to response preparation (LRP), appeared to be influenced by strategic emphasis on the phonemic judgments. As a consequence, predicted LRP effects (specifically on NoGo trials) were not detected, and the LRP data could not be used to compute the real-time availability of semantic versus phonological information in either group. However, the NoGo LRP results did serve to demonstrate how strategic response preparation might come about in a language production task, a potential confound that was noted in the Introduction.

Results from this investigation contribute to a larger body of evidence showing that aspects of language processing can operate differently in AWS versus TFA. In the current task, semantic information influenced response inhibition more slowly in AWS versus TFA. Slowed speed of semantic encoding in AWS, in turn, raises several questions for future research. Specifically, do attentional decrements, a less mature lexical-semantic framework, and/or chronic word substitution behaviors slow semantic encoding in AWS? In addition, might slowed semantic encoding impact fluency in AWS via semantic or lexical errors detected covertly and trigger immediate/within-word interruptions?

Finally, results of this study and other research before it raise the question of whether language production should be targeted in therapy for stuttering along with the usual focus on establishing speech motor control and addressing emotional aspects of experience with stuttering (see Bothe et al., 2006). As discussed in Maxfield et al. (2016), a traditional approach to stuttering intervention often does involve modifying language production behavior in AWS (via identification and elimination of verbal secondary behaviors). However, the extent to which such procedures for stabilizing language production behavior actually contribute to reductions in stuttering is unknown.

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References

- Arnstein, D., Lakey, B., Compton, R. J., & Kleinow, J. (2011). Preverbal error-monitoring in stutterers and fluent speakers. *Brain and Language*, 116(3), 105–115.
- Bajaj, A. (2007). Working memory involvement in stuttering: Exploring the evidence and research implications. *Journal of Fluency Disorders*, 32(3), 218–238.
- Bakker, K., & Brutten, G. J. (1989). A comparative investigation of the laryngeal premotor, adjustment, and reaction times of stutterers and nonstutterers. *Journal of Speech, Language, and Hearing Research*, 32(2), 239–244.
- Bell, A. J., & Sejnowski, T. J. (1995). An information-maximization approach to blind separation and blind deconvolution. *Neural Computation*, 7(6), 1129–1159.
- Blackmer, E. R., & Mitton, J. L. (1991). Theories of monitoring and the timing of repairs in spontaneous speech. *Cognition*, 39(3), 173–194.
- Bloodstein, O., & Bernstein-Ratner, N. (2008). *A handbook on stuttering* (6th ed.). New York, NY: Thomson-Delmar.
- Bock, K. (1996). Language production: Methods and methodologies. *Psychonomic Bulletin & Review*, 3(4), 395–421.
- Bokura, H., Yamaguchi, S., & Kobayashi, S. (2001). Electrophysiological correlates for response inhibition in a Go/NoGo task. *Clinical Neurophysiology*, 112(12), 2224–2232.
- Bosshardt, H. G. (2006). Cognitive processing load as a determinant of stuttering: Summary of a research programme. *Clinical Linguistics & Phonetics*, 20(5), 371–385.
- Bosshardt, H.-G., & Fransen, H. (1996). Online sentence processing in adults who stutter and adults who do not stutter. *Journal of Speech, Language, and Hearing Research*, 39(4), 785–797.
- Bosshardt, H.-G., & Nandyal, I. (1988). Reading rates of stutterers and nonstutterers during silent and oral reading. *Journal of Fluency Disorders*, 13(6), 407–420.
- Bothe, A. K., Davidow, J. H., Bramlett, R. E., & Ingham, R. J. (2006). Stuttering treatment research 1970–2005: I. Systematic review incorporating trial quality assessment of behavioral, cognitive, and related approaches. *American Journal of Speech-Language Pathology*, 15(4), 321–341.
- Burger, R., & Wijnen, F. (1999). Phonological encoding and word stress in stuttering and nonstuttering subjects. *Journal of Fluency Disorders*, 24(2), 91–106.
- Coles, M. G., Smid, H. G., Scheffers, M. K., & Otten, L. J. (1995). Mental chronometry and the study of human information processing. In M. D. Rugg, & M. G. Coles. (Eds.), *Electrophysiology of mind: event-related brain potentials and cognition* (pp. 86–131). Oxford, United Kingdom: Oxford University Press.
- Coles, M. G., Gratton, G., & Donchin, E. (1988). Detecting early communication: Using measures of movement-related potentials to illuminate human information processing. *Biological Psychology*, 26(1), 69–89.
- Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, 82(6), 407–428.
- Constantino, C. D., Leslie, P., Quesal, R. W., & Yaruss, J. S. (2016). A preliminary investigation of daily variability of stuttering in adults. *Journal of Communication Disorders*, 60, 39–50.
- Crowe, K. M., & Kroll, R. M. (1991). Response latency and response class for stutterers and nonstutterers as measured by a word-association task. *Journal of Fluency Disorders*, 16(1), 35–54.
- Daliri, A., & Max, L. (2015). Modulation of auditory processing during speech movement planning is limited in adults who stutter. *Brain and Language*, 143, 59–68.
- Dell, G. S., & O'Seaghdha, P. G. (1992). Stages of lexical access in language production. *Cognition*, 42(1), 287–314.
- Dunn, D. M., & Dunn, L. M. (2007). *Peabody Picture Vocabulary Test: Manual*. San Antonio, TX: Pearson.

- Eggers, K., De Nil, L. F., & Van den Bergh, B. R. (2009). Factorial temperament structure in stuttering, voice-disordered, and typically developing children. *Journal of Speech, Language, and Hearing Research*, 52(6), 1610–1622.
- Fuster, J. M. (2001). The prefrontal cortex—An update: Time is of the essence. *Neuron*, 30(2), 319–333.
- Ganushchak, L. Y., Christoffels, I. K., & Schiller, N. O. (2011). The use of electroencephalography in language production research: A review. *Frontiers in Psychology*, 2, 208.
- Glaser, W. R. (1992). Picture naming. *Cognition*, 42(1), 61–105.
- Glass, K. A., Frishkoff, G. A., Frank, R. M., Davey, C., Dien, J., Malony, A. D., & Tucker, D. M. (2004). A framework for evaluating ICA methods of artifact removal from multichannel EEG. In C. G. Puntonet & A. Prieto (Eds.), *Independent component analysis and blind signal separation* (pp. 1033–1040). Berlin/Heidelberg, Germany: Springer.
- Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, 121(4), 480–506.
- Hand, C. R., & Haynes, W. O. (1983). Linguistic processing and reaction time differences in stutterers and nonstutterers. *Journal of Speech, Language, and Hearing Research*, 26(2), 181–185.
- Hartfield, K. N., & Cunture, E. G. (2006). Effects of perceptual and conceptual similarity in lexical priming of young children who stutter: Preliminary findings. *Journal of Fluency Disorders*, 31(4), 303–324.
- Hartsuiker, R. J., & Kolk, H. H. (2001). Error monitoring in speech production: A computational test of the perceptual loop theory. *Cognitive Psychology*, 42(2), 113–157.
- Hauk, O., Patterson, K., Woollams, A., Cooper-Pye, E., Pulvermüller, F., & Rogers, T. T. (2007). How the camel lost its hump: The impact of object typicality on event-related potential signals in object decision. *Journal of Cognitive Neuroscience*, 19(8), 1338–1353.
- Healey, E. C. (2010, November). What the literature tells us about listeners' reactions to stuttering: Implications for the clinical management of stuttering. In *Seminars in speech and language* (Vol. 31, No. 04, pp. 227–235). New York, NY: Thieme Medical Publishers.
- Hennessey, N. W., Nang, C. Y., & Beilby, J. M. (2008). Speeded verbal responding in adults who stutter: Are there deficits in linguistic encoding? *Journal of Fluency Disorders*, 33(3), 180–202.
- Howell, P. (2004). Assessment of some contemporary theories of stuttering that apply to spontaneous speech. *Contemporary Issues in Communication Science and Disorders: CICSD*, 31, 122–139.
- Jensen, P. J., Markel, N. N., & Bevering, J. W. (1986). Evidence of conversational dysrhythmia in stutterers. *Journal of Fluency Disorders*, 11(3), 183–200.
- Jescheniak, J. D., & Levelt, W. J. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20(4), 824–843.
- Johnson, J. S., & Olshausen, B. A. (2005). The earliest EEG signatures of object recognition in a cued-target task are post-sensory. *Journal of Vision*, 5(4), 299–312.
- Jones, R. M., Fox, R. A., & Jacewicz, E. (2012). The effects of concurrent cognitive load on phonological processing in adults who stutter. *Journal of Speech, Language, and Hearing Research*, 55(6), 1862–1875.
- Kami, M. K., Shine, R. E., & Rastatter, M. P. (2000). Stutterers' vocal reaction times to unilaterally presented high and low frequency verbs. *Perceptual and Motor Skills*, 91(1), 123–130.
- Karniol, R. (1995). Stuttering, language, and cognition: A review and a model of stuttering as suprasegmental sentence plan alignment (SPA). *Psychological Bulletin*, 117(1), 104–124.
- Kempen, G., & Hoenkamp, E. (1987). An incremental procedural grammar for sentence formulation. *Cognitive Science*, 11(2), 201–258.
- Kirchner, H., & Thorpe, S. J. (2006). Ultra-rapid object detection with saccadic eye movements: Visual processing speed revisited. *Vision Research*, 46(11), 1762–1776.
- Klem, G. H., Lüders, H. O., Jasper, H. H., & Elger, C. (1999). The ten–twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology*, 52(Suppl.), 3–6.
- Kutas, M., & Donchin, E. (1974). Studies of squeezing: Handedness, responding hand, response force, and asymmetry of readiness potential. *Science*, 186(4163), 545–548.
- Kutas, M., & Donchin, E. (1980). Preparation to respond as manifested by movement-related brain potentials. *Brain Research*, 202(1), 95–115.
- Levelt, W. J. (1983). Monitoring and self-repair in speech. *Cognition*, 14(1), 41–104.
- Levelt, W. J. (1984). Spontaneous self-repairs in speech: Processes and representations. In *10th International Congress of Phonetic Sciences* (pp. 105–117). Utrecht, Netherlands: Foris.
- Levelt, W. J. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.
- Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22(01), 1–38.
- Liu, H., Agam, Y., Madsen, J. R., & Kreiman, G. (2009). Timing, timing, timing: Fast decoding of object information from intracranial field potentials in human visual cortex. *Neuron*, 62(2), 281–290.
- Maxfield, N. D., Huffman, J. L., Frisch, S. A., & Hinckley, J. J. (2010). Neural correlates of semantic activation spreading on the path to picture naming in adults who stutter. *Clinical Neurophysiology*, 121(9), 1447–1463.
- Maxfield, N. D., Morris, K., Frisch, S. A., Morphew, K., & Constantine, J. L. (2015). Real time processing in picture naming in adults who stutter: ERP evidence. *Clinical Neurophysiology*, 126(2), 284–296.
- Maxfield, N. D., Olsen, W. L., Kleinman, D., Frisch, S. A., Ferreira, V. S., & Lister, J. J. (2016). Attention demands of language production in adults who stutter. *Clinical Neurophysiology*, 127(4), 1942–1960.
- Maxfield, N. D., Pizon-Moore, A. A., Frisch, S. A., & Constantine, J. L. (2012). Exploring semantic and phonological picture–word priming in adults who stutter using event-related potentials. *Clinical Neurophysiology*, 123(11), 1131–1146.
- McClure, J. A., & Yaruss, J. S. (2003). Stuttering survey suggests success of attitude-changing treatment. *The ASHA Leader*, 8(3), 19.
- Meyer, D. E., Osman, A. M., Irwin, D. E., & Yantis, S. (1988). Modern mental chronometry. *Biological Psychology*, 26(1), 3–67.
- Murase, S., Kawashima, T., Satake, H., & Era, S. (2016). An event-related potential investigation of sentence processing in adults who stutter. *Neuroscience Research*, 106, 29–37.
- Newman, R. S., & Bernstein Ratner, N. (2007). The role of selected lexical factors on confrontation naming accuracy, speed, and fluency in adults who do and do not stutter. *Journal of Speech, Language, and Hearing Research*, 50(1), 196–213.
- Nippold, M. A. (2012). Stuttering and language ability in children: Questioning the connection. *American Journal of Speech-Language Pathology*, 21(3), 183–196.
- Nooteboom, S. G. (1980). Speaking and unspeaking: Detection and correction of phonological and lexical errors in spontaneous speech. In V. A. Fromkin (Ed.), *Errors in linguistic performance* (pp. 87–95). New York, NY: Academic Press.

- Nunez, P. L., & Srinivasan, R. (2006). *Electric fields of the brain: The neurophysics of EEG*. New York, NY: Oxford University Press.
- Perkins, W. H., Kent, R. D., & Curlee, R. F. (1991). A theory of neuropsycholinguistic function in stuttering. *Journal of Speech and Hearing Research*, 34(4), 734–752.
- Peters, H. M., Hulstijn, W., & Van Lieshout, P. H. (2000). Recent developments in speech motor research into stuttering. *Folia Phoniatrica et Logopaedica*, 52(1–3), 103–119.
- Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, 35, 73–89.
- Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, 37(2), 127–152.
- Postma, A., & Kolk, H. (1993). The covert repair hypothesis pre-articulatory repair processes in normal and stuttered disfluencies. *Journal of Speech, Language, and Hearing Research*, 36(3), 472–487.
- Postma, A., Kolk, H., & Povel, D. J. (1990). Speech planning and execution in stutterers. *Journal of Fluency Disorders*, 15(1), 49–59.
- Prins, D., Main, V., & Wampler, S. (1997). Lexicalization in adults who stutter. *Journal of Speech, Language, and Hearing Research*, 40(2), 373–384.
- Rahman, R. A., & Sommer, W. (2003). Does phonological encoding in speech production always follow the retrieval of semantic knowledge? Electrophysiological evidence for parallel processing. *Cognitive Brain Research*, 16(3), 372–382.
- Rahman, R. A., Van Turenout, M., & Levelt, W. J. (2003). Phonological encoding is not contingent on semantic feature retrieval: An electrophysiological study on object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29(5), 850–860.
- Rastatter, M. P., & Dell, C. W. (1987). Reaction times of moderate and severe stutterers to monaural verbal stimuli: Some implications for neurolinguistic organization. *Journal of Speech and Hearing Research*, 30(1), 21–27.
- Rochford, E. B. (1983). Stutterers' practices: Folk remedies and therapeutic intervention. *Journal of Communication Disorders*, 16(5), 373–384.
- Rodriguez-Fornells, A., Schmitt, B. M., Kutas, M., & Münte, T. F. (2002). Electrophysiological estimates of the time course of semantic and phonological encoding during listening and naming. *Neuropsychologia*, 40(7), 778–787.
- Roelofs, A. (1997). The WEAVER model of word-form encoding in speech production. *Cognition*, 64(3), 249–284.
- Sasisekaran, J., De Nil, L. F., Smyth, R., & Johnson, C. (2006). Phonological encoding in the silent speech of persons who stutter. *Journal of Fluency Disorders*, 31(1), 1–21.
- Schmitt, B. M., Münte, T. F., & Kutas, M. (2000). Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. *Psychophysiology*, 37(4), 473–484.
- Seyfeddinipur, M., Kita, S., & Indefrey, P. (2008). How speakers interrupt themselves in managing problems in speaking: Evidence from self-repairs. *Cognition*, 108(3), 837–842.
- Smid, H. G., Mulder, G., Mulder, L. J., & Brands, G. J. (1992). A psychophysiological study of the use of partial information in stimulus-response translation. *Journal of Experimental Psychology: Human Perception and Performance*, 18(4), 1101–1119.
- Strijkers, K., Holcomb, P. J., & Costa, A. (2011). Conscious intention to speak proactively facilitates lexical access during overt object naming. *Journal of Memory and Language*, 65(4), 345–362.
- Szekely, A., Jacobsen, T., D'Amico, S., Devescovi, A., Andonova, E., Herron, D., . . . Bates, E. (2004). A new on-line resource for psycholinguistic studies. *Journal of Memory and Language*, 51(2), 247–250.
- Taylor, W. L., Lore, J. I., & Waldman, I. N. (1970, September). Latencies of semantic aphasics, stutterers, and normal controls to cloze items requiring unique and non-unique oral responses. In *Proceedings of the Annual Convention of the American Psychological Association* (Vol. 78, pp. 75–76). Washington, DC: American Psychological Association.
- Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature*, 381(6582), 520–522.
- Tydgat, I., Stevens, M., Hartsuiker, R. J., & Pickering, M. J. (2011). Deciding where to stop speaking. *Journal of Memory and Language*, 64(4), 359–380.
- Van Rullen, R., & Thorpe, S. J. (2002). Surfing a spike wave down the ventral stream. *Vision Research*, 42(23), 2593–2615.
- van Turenout, M., Hagoort, P., & Brown, C. M. (1997). Electrophysiological evidence on the time course of semantic and phonological processes in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23(4), 787–806.
- van Turenout, M., Hagoort, P., & Brown, C. M. (1998). Brain activity during speaking: From syntax to phonology in 40 milliseconds. *Science*, 280(5363), 572–574.
- Vanryckeghem, M., Brutton, G. J., Uddin, N., & Van Borsel, J. (2004). A comparative investigation of the speech-associated coping responses reported by adults who do and do not stutter. *Journal of Fluency Disorders*, 29(3), 237–250.
- Vasic, N., & Wijnen, F. N. K. (2005). Stuttering as a monitoring deficit. In R. J. Hartsuiker, R. Bastiaanse, A. Postma, & F. Wijnen (Eds.), *Phonological encoding and monitoring in normal and disordered speech* (pp. 226–247). Hove, United Kingdom: Psychology Press.
- Walker, G. M., & Hickok, G. (2016). Bridging computational approaches to speech production: The semantic-lexical-auditory-motor model (SLAM). *Psychonomic Bulletin & Review*, 23(2), 339–352.
- Weber-Fox, C., & Hampton, A. (2008). Stuttering and natural speech processing of semantic and syntactic constraints on verbs. *Journal of Speech, Language, and Hearing Research*, 51(5), 1058–1071.
- Weber-Fox, C., Spencer, R. M., Spruill, J. E., III, & Smith, A. (2004). Phonologic processing in adults who stutter: Electrophysiological and behavioral evidence. *Journal of Speech, Language, and Hearing Research*, 47(6), 1244–1258.
- Williams, K. T. (2007). *EVT-2: Expressive Vocabulary Test*. San Antonio, TX: Pearson Assessments.
- Wingate, M. E. (1964). A standard definition of stuttering. *Journal of Speech and Hearing Disorders*, 29(4), 484–489.
- Wingate, M. E. (1988). *The structure of stuttering: A psycholinguistic approach*. New York, NY: Springer-Verlag.
- Yairi, E., & Ambrose, N. (2013). Epidemiology of stuttering: 21st century advances. *Journal of Fluency Disorders*, 38(2), 66–87.
- Yaruss, J. S., & Quesal, R. W. (2006). Overall Assessment of the Speaker's Experience of Stuttering (OASES): Documenting multiple outcomes in stuttering treatment. *Journal of Fluency Disorders*, 31(2), 90–115.
- Zhang, Q., Damian, M. F., & Yang, Y. (2007). Electrophysiological estimates of the time course of tonal and orthographic encoding in Chinese speech production. *Brain Research*, 1184, 234–244.