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Brain electrophysiological correlates of masked picture priming in fluent and stuttering adults

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by

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Abstract

Objective: The aim of the present study was to investigate mechanisms of real-time language production of adults who stutter.

Method: Data were analyzed for 19 typically fluent young adults (TFA) and 19 young adults who stutter (AWS). Participants performed a masked picture priming task where priming stimuli consisted of two conditions 1) Identity- a masked printed prime word identical to the picture target label, and 2) Unrelated- a masked printed prime word unrelated to the picture target label. Brain event-related potentials (ERPs), time-locked to pictures eliciting spontaneous naming, were recorded, as well as naming accuracy and reaction times.

Results: Masked priming effects on ERP components were compared between groups. Priming modulated N400 amplitude in TFA while, at the same latency, priming modulated P300 amplitude in AWS. N400 is attributed to processing of meaningful stimuli, and P300 is a measure of effortful control. An even later priming effect generalized to both groups.

Conclusion: Results suggest that post-lexical processing was similar in AWS and TFA, while lexical-semantic processing operated differently. Whereas TFA evidenced automaticity in activation and selection of target picture labels, AWS evidenced enhanced attentional control during lexical selection. We propose that AWS recruited a compensatory attentional mechanism to stabilize activation of target words on the path to naming. These conclusions suggest that clinically, AWS may benefit from vocabulary enrichment and attentional control treatment.

Introduction

Due to disagreement in the underlying nature of stuttering, along with the many variables that encompass it, this complex disorder is not easily defined. Traditionally, it has been defined as disrupted “moments” of speech characterized by repetitions, blocks and prolongations. However, one should be careful not to neglect the other physical and psychological concomitant behaviors that accompany stuttering (Bloodstein & Bernstein Ratner, 2008). The prevalence of stuttering in adults ages 21-50 is .78% with a 2.2 to 1 male-to-female ratio, according to Craig, Hancock, Tran, Craig, & Peters (2002). Based on the 2010 U.S. Census, this equates to roughly 1,500,000 adults in the United States that stutter. This is consistent with previous reviews of the prevalence of stuttering which provided an overall estimate of approximately 1 percent (Bloodstein & Bernstein Ratner, 2008).

With approximately 1,500,000 adults in the United States living with this disorder, examining the impact it has on quality of life demonstrates the significance of further research in the area of stuttering. According to Yaruss (2010), adults who stutter (AWS) reported that stuttering has a negative impact on their quality of life, including, but not limited to, their overall quality of life, and their satisfaction with communication, employment, and relationships. Impact level is thought to vary due to the severity of the stuttering, prior participation in treatment, and self-help (Yaruss, 2010). Other quality of life studies have found similar results. For example, through the administration of The Medical Outcomes Study Short-Form 36-Item Health Survey (SF-36), a standard quality of life measure, Craig, Blumgart, & Tran (2009) showed that stuttering negatively impacted vitality, social, emotional and mental functioning. Blumgart, Tran, & Craig (2010) found that when evaluating levels of anxiety, AWS were significantly more anxious and had a significantly greater number of social phobia symptoms than typically fluent adults (TFA). This is evident in a personal account from an AWS, Dr. Frederick Murray, as he recalls his attempt to enlist in the navy; “Since the previous November, when I had tried unsuccessfully to enlist in the navy, I had lost much of my never-very-abundant confidence, and I wondered what good I could do for my country when I was stuttering my head off this way” (Murray & Edwards, 1980, p. 55).

Given this information it is interesting to note that of 2,000 speech-language pathologists who were surveyed about their attitudes toward stuttering, over three-fourths agreed that the majority of clinicians are not competent in the area of fluency treatment (Cooper & Cooper, 1996). The authors of this study believe that this shows a great need for enhanced education in the area of stuttering. Yaruss and Bernstein Ratner (2010) attribute clinician’s discomfort level to the idea that because the knowledge about the underpinnings of this disorder have continued to change with recent research, the treatment for stuttering therefore must evolve with the current findings. This poses a challenge for clinicians to maintain their knowledge of the current research in not only treatment effectiveness and techniques with people who stutter, but with the etiology behind stuttering, since this impacts treatment.

There are many different theories and models of stuttering to consider. Some models focus on the breakdown that occurs at the moment of stuttering, while other models focus on the underlying cause or etiology of stuttering. It is thought that stuttering can be caused by psychological, environmental, and/or physiological factors (Bloodstein & Bernstein Ratner, 2008). Current models of stuttering integrate these features into one model. Within Conture et al.’s (2006) Communication-Emotional Model of Stuttering, there are three different levels of these etiological features. The first level is composed of distal contributors of stuttering, which includes the influences of genetics and the environment. The second level is broken down into proximal contributors of stuttering, which includes the production and planning of speech and language. The final level considers the factors which can exacerbate stuttering: emotional reactivity and regulation (Conture et al., 2006). Components of the Communication-Emotional model are well studied. For example, in the area of proximal contributors of stuttering, there is substantial evidence behind the idea that the motor abilities of people who stutter are different than people who do not stutter. Studies have found limitation and slowness of movement, as well as discoordination of the articulators and larynx during speech production (Bloodstein & Bernstein Ratner, 2008; Jones, Fox, & Jacewicz, 2012). Other aspects of the Communication-Emotional model such as, language processing skills are not as well established and more research is needed in this area.

The aim of this study is to extend our current knowledge of how AWS process their linguistic knowledge when they speak. In the sections below I will first give an overview of current models of language processing during speech production. This will provide insight as to how the brain processes lexical knowledge when naming pictures, as well as emphasize the crucial role that efficient language processing has in producing speech fluently. Then, I will present current behavioral evidence of linguistic processing in AWS and explain why behavioral techniques are limited in studying lexical retrieval in this population. Lastly, I will give background information on electrophysiological techniques for studying linguistic processing during speech production. I will also provide reasoning as to why this study extended upon existing work, utilizing a masked priming method to study word retrieval during picture naming.

Language Processing During Speech Production

In TFA, words are rapidly retrieved from a mental lexicon consisting of about 30,000 words (Cutting & Ferreira, 1999). More impressively, according to Levelt (1989), TFA are able to access that vast lexicon so efficiently that they can produce approximately 150 words per minute with an average of only one error for every 1,000 words produced. The complexity of speech production is often overlooked because of this proficiency.

Mechanistically, speech production begins with the generation of an idea or message in which the speaker must 1) access the semantic components and 2) access the phonological components of the message before planning out the motor movements to convey their thought (Caramazza, 1997; Cutting & Ferreira, 1999; Dell, 1986; Dell & O'Seaghdha, 1992; Ferriera & Pashler, 2002; Levelt, 1999). This two stage model of lexical access is foundational across the various models of speech production (Caramazza, 1997). A model that operationalizes this process is the spreading activation theory. This theory sees the lexicon as a network rather than a listing, so there are nodes or memory units for each linguistic unit and connections between these nodes (Dell, 1986). Our linguistic memory can be thought of as a hierarchy in which there are different levels of linguistic knowledge (i.e., conceptual features, whole word representations, sound representations). Though each of these levels is represented independently, they are connected through networks. According to the spreading activation theory of word production, we first activate the conceptual-semantic features of the word we are selecting. For example, if a speaker is attempting to select the word *couch* from his/her mental lexicon, conceptual-semantic features such as *soft*, *four legs, pillow, etc.* may be activated (Level 1 of Figure 1). These conceptual features then spread activation to words, or lemmas which are associated with these concepts (i.e. *couch, bed, bend*) (Level 2 of Figure 1). The lemma of a word is thought to comprise information about the word's syntactic or grammatical features. The activated lemma then spreads activation to the phonological representation of the word, or its lexeme (Level 3 of Figure 1). The lexeme represents the whole word sound properties or the phonological word form. Lastly, activation spreads from the *lexeme* to the phoneme representation which is comprised of the specific sound segments of the word (Level 4 of Figure 1) (Caramazza, 1997; Cutting & Ferreira, 1999; Dell, 1986; Dell & O'Seaghdha, 1992; Ferriera & Pashler, 2002; Levelt, 1999).

It should be noted that there are different views on the directionality of activation spreading in this model. According to Levelt et al. (1999), the levels are discrete in that when producing a word, one must first choose a winning lemma, and only once the most highly activated lemma is chosen can phonological encoding begin. However, according to Dell (1989), who believes the levels are interactive, the whole-word representation and individual phonemes can be activated simultaneously, without a winning lemma, and can spread activation back up to the lemma. Another view is that activation of the lemma and whole-word phonological features, the lexeme, are drawn from domain general cognitive resources, where as the phonological features of a word are drawn from a modular resource used only for linguistic processing (Ferriera & Pashler, 2002). This view suggests that the initial three levels of the model, shown in Figure 1, are processed along with non-linguistic cognitive processes, and the bottom level is processed exclusively with other linguistic processes and does not share resources with other cognitive processes.

It is crucially important to recognize that fluent speech is dependent upon the process of lexical access working well and effectively (Levelt, 1989); however, this prerequisite for fluent speech has had less research emphasis placed on it as compared to the motor planning process. An extreme example of this "breakdown" in speech is anomia or word retrieval difficulty. Maher and Raymer (2004) proposed that there is a breakdown in lexical activation during anomia that can occur at one or a combination of the processing levels discussed above. With both stuttering and anomia, the fluency of expression is experiencing a breakdown at some linguistic level. We acknowledge that anomia is not analogous to stuttering, but it is interesting to consider that stuttering may be a more subtle example of fluency breakdown as compared to anomia.

Current Evidence of Linguistic Processing in AWS

Research suggests that linguistic processing in AWS may be different than that of TFA, but the literature in this area is limited in not only the number of studies completed, but in the methods used. Many researchers agree that there is some type of disturbance or deviation in the process of lexical access in AWS, but what is not known is where that breakdown occurs (Bosshardt & Fransen, 1996; Newman & Bernstein Ratner, 2007; Postma & Kolk, 1993; Prins & Main, 1997; Watson et al., 1994; Wijnen & Boers, 1994).

Current evidence exploring linguistic processing in AWS sheds light on what is occurring at the level of semantic activation. AWS were found to be equally as fast (Crowe & Kroll, 1991) or faster (Jensen, Markel, & Beverung, 1986) in their response times to tests of word association as compared to TFA. This would suggest that semantic activation spreading is efficient in AWS. Through a silent reading task, AWS were slower when monitoring for category-specific words, suggesting that semantic activation spreading is processed more slowly in AWS than TFA (Bosshardt & Fransen, 1996). During confrontation naming, AWS were found to be less accurate than TFA. This could mean that the AWS are having difficulty accessing semantic concepts, which in turn hinders activation of lemmas while naming (Newman & Bernstein Ratner, 2007; also see Van Lieshout, Hulstijn, & Peters, 1996; Hennessey, Nang, & Beilby, 2008). Deficits similar to those described above have also been seen during receptive language tasks (Watson et al., 1994; Prins & Main, 1997).

Current evidence also provides us with suggestions about what is occurring during linguistic processing at the level of phonological activation in AWS. When looking at spoken reaction times with and without phonological priming, AWS had slower spoken reaction times overall as compared to TFA; however, AWS showed evidence of phonological priming through their faster spoken reaction times when given a phonological prime word versus an unrelated prime word (Burger & Wijnen, 1999; Hennessey et al., 2008; Vincent, Grela, & Gilbert, 2012).

This suggests that AWS do not have trouble accessing phonological forms (Newman & Bernstein Ratner, 2007). Sasisekaran, De Nil, Smyth, &Johnson (2006) had AWS and TFA complete a set of tasks, which included phoneme and tone monitoring, as well as overt naming. They found that AWS performed equally to the TFA in all tasks except for phoneme monitoring, in which they were slower. This suggests that activation of phonological representations in AWS is slower than in TFA. Bosshardt & Nandyal (1988) found that AWS had longer reading times per word and per syllable during both silent and oral reading suggesting that “AWS differ in basic processing time for verbal material” (Bosshardt & Nandyal, 1988, p. 407) (also see Postma, Kolk, & Povel, 1990). AWS also had slower naming latencies for lower frequency words than TFA (Prins & Main, 1997; Newman & Bernstein Ratner, 2007), and were more disfluent in low frequency words (Hubbard & Prins, 1994). Also, during tongue twisters, AWS produced more word onset and word-order errors than TFA (Brocklehurst & Corley, 2011; Eldridge & Felsenfield, 1998). These results suggest that phonological competition resolves more slowly and less accurately in AWS than in TFA. Lastly, Smith, Sadagopan, Walsh and Weber-Fox (2012) investigated the effects of concurrent cognitive load on phonological processing in AWS using a dual task, and concluded that phonological processing in AWS is more vulnerable to breakdown with increased cognitive load (also see Byrd, Vallely, Anderson, & Sussman, 2012)

Brain Electrophysiological Techniques for Studying Linguistic Processing During Speech Production

Though the behavioral studies reviewed above point toward weak linguistic processing at some level in AWS, these studies are limited due to the nature of the behavioral methods used. Non-linguistic factors such as “motor abilities, metalinguistic skills, and/or preferences-for-responding” (Maxfield, Huffman, Frisch, & Hinckley, 2010, p. 1448) were not controlled for when using behavioral techniques. For example, if looking at reaction times in a picture naming study, conclusions about the speed in which AWS name the pictures presented may not necessarily be indicative of speed of processing at a specific linguistic level due to their limited motor abilities. In order to reduce these extraneous factors, we have chosen to use event related potentials (ERPs), which are event-related changes in the brain's electrical activity recorded on the scalp, to look at processing during lexical access in AWS. Unlike traditional behavioral measures, such as reaction time measures, ERPs are both a "continuous" and "real time" measure. This makes it possible to monitor the "…immediate consequences of a particular experimental manipulation" (Hagoort & Kutas, 1995, p. 109). This electrical activity that is recorded on the scalp can be generated from internal or external events and captures rapid changes online (Otten & Rugg, 2005). ERP, a brain imaging technique, provides a high temporal resolution that allows information to be gathered about brain processes involved in various cognitive acts (Hagoort & Kutas, 1995; Meyer, Osman, Irwin, & Yantis, 1988). Through looking at the three main aspects of ERPs: 1) time course 2) amplitude and 3) distribution across the scalp, one can make inferences about the "…timing, degree of engagement, and functional equivalence of the underlying cognitive processes" (Otten & Rugg, 2005, p. 5). Many studies have sought to correlate specific features of ERP waveforms with particular cognitive processes (Otten & Rugg, 2005; Van Petten & Kutas, 1991). One example is the N400 component, which has been closely associated with language processing, and shown to be elicited by lexical stimuli (Fischler, 1990; Otten & Rugg, 2005; Hagoort & Kutas, 1995).

Weber-Fox (2001) has explored the use of ERPs in studying language processing in AWS; however, she chose to use a methodology which eliminated speech production demands. Her participants were presented with sentences to read word by word on a computer screen, then they were asked to respond with "yes" the sentence made sense or "no" the sentence did not make sense by pressing corresponding buttons on a response box. Weber-Fox and Hampton (2008) also studied language processing in AWS during an auditory sentence task where participants listened to a sentence and judged whether it was a good English sentence and made sense. In both of these studies the neural activity of the AWS was found to be different than that of the TFA, indicating that the underlying neural activity for processing language is atypical in AWS (Weber-Fox & Hampton, 2008). It should be noted that these studies used comprehension tasks to explore linguistic processing in AWS; however, ERPs are not limited to comprehension tasks. They can be utilized to investigate processing during speech production tasks, which are a more naturalistic type of task.

Various techniques using ERPs to study language processing, on the path to speech production, have been employed over the past decade or so. For example, in order to investigate the time course of different levels of linguistic processing, several studies from 1997-2001 used dual-choice lexical decision tasks. The dual-choice lexical decision paradigm requires the participant to make two choices about the stimuli presented (typically, a picture): 1) Semantic or grammatical aspects of the picture, such as its animacy; and 2) phonological aspects of the label of the picture. Participants are required to map these lexical decisions onto specific hand movements. Depending on one attribute of the stimuli (i.e., their animacy), they will respond or not respond and 2) depending on another specified attribute of the stimuli (i.e., their phonological characteristics), they will respond with their left-hand or right-hand (Schmitt, Schiltz, Zaake, Kutas, & Munte, 2001; Van Turennout, Hagoort, & Brown, 1997, 1999). Through this paradigm, an ERP waveform referred to as the Lateralized Readiness Potential (LRP) can be elicited and "…used to detect the relative moments at which distinct kinds of information become available for response preparation" (Van Turennout et al., 1999, p. 653). Studies using this paradigm have shown that, in real-time, on the path to picture-naming, conceptual/semantic information becomes available prior to syntactic information (Schmitt et al., 2001), semantic activation precedes phonological encoding (Van Turennout et al., 1997), and grammatical processing precedes phonological processing (Van Turennout et al., 1999). These conclusions are important in understanding when, on a milliseconds-scale, the different, independent levels of the mental lexicon become activated on the path to lexical access and, ultimately, naming.

Another experimental paradigm used to study mechanisms of lexical retrieval is picture-word priming. This technique was first implemented by Jescheniak, Schriefers, Garrett, & Friederici (2002) in order to explore semantic and phonological activation in speech production. Participants were presented with a picture, asked to wait to name the picture until prompted, and while they prepared to produce the name of the picture, an auditory probe word was played. The probe was either semantically or phonologically related to the picture label, or unrelated to the picture label. Jescheniak et al. (2002) recorded ERPs to the auditory probe word because at this time "preparation of the naming response should lead to activation of the corresponding semantic and phonological information in the lexical-conceptual system" p. 953. Results of this study revealed priming effects for both the phonologically and semantically related probe words, with the phonological effects showing up earlier than the semantic effects and attenuation of N400 activity during both of these conditions.

Maxfield et al. (2010) also implemented a modified version of this experimental paradigm comparing AWS and TFA to see if differences existed in semantic activation spreading between the two groups. Participants heard auditory probe words that were either semantically related to the picture label, but had no phonological relation; semantically unrelated, but overlapped in the words initial phoneme; or an unrelated probe word which had no initial phonological or semantic overlap to the picture label. ERPs were recorded at the auditory probe word as seen in Jescheniak et al. (2002) and average ERPs for the semantically related and unrelated conditions were compared. It was found that in TFA, posterior N400 amplitude was attenuated for the semantically related probes versus the unrelated probes; however, in AWS the posterior N400 amplitude was enhanced for the semantically related probes.

It is suggested that this could be because “AWS allocated attentional resources differently” (Maxfield et al, 2010, p. 1447).

Maxfield, Pizon-Moore, Frisch, & Constantine (2012) extended upon the Maxfield et al. (2010) study and modeled their design more closely to Jescheniak et al. (2002) in order to further investigate how semantic and phonological information is processed in AWS. With the addition of a phonological condition and a probe word verification check for each critical trial, the investigators found typical priming effects for the TFA, but diminished semantic priming and reverse phonological N400 priming for the AWS. The results of both Maxfield et al. (2010) and Maxfield et al. (2012) suggest that linguistic processing, specifically at the semantic and phonological level, are atypical in AWS. One of the limitations of utilizing the picture-word priming paradigm is that this is a fairly offline task. Though ERPs are an online measure, in this paradigm, ERPs time locked to the auditory probe words are being measured in order to make inferences about how the preceding pictures were processed. Also, atypical phonological working memory demands are placed on the participants by 1) delaying naming and 2) asking them to remember and verify an auditory probe word. Therefore, it is possible that atypical results seen for AWS were, at least in part, task artifacts. Adopting a paradigm which allows for investigation of language processing in AWS, during, rather than immediately after picture naming was a significant next step.

In order to expand on this evidence that differences in linguistic processing exist between AWS and TFA, we chose to modify the masked priming paradigm used by Chauncey, Holcomb & Grainger (2009). Picture-naming has been recognized as a popular behavioral measure to research single-word production. Masked priming allows the researcher to better control priming stimuli since the participant is less aware of the prime word and therefore, cannot develop strategies when naming. This paradigm is meant to facilitate more precise tracking of the interaction between the prime and target words by limiting the participant’s attention to the prime word. The combination of these two methodologies, picture-naming and masked priming, with the use of ERPs, may allow for a deeper look into the relative timing of underlying processes during primed picture naming. Masked priming also eliminates delayed naming and dual attention (to the picture and auditory probe), as used in Jescheniak et al. (2002), Maxfield et al. (2010) and Maxfield et al. (2012). Participants are instructed to name the picture as soon as it is presented and do not have to pay attention to any stimuli other than what is presented on the screen, first the masked prime word and then the picture. This allows for a cleaner design with attention allocated to a single stimulus.

Chauncey et al.'s (2009) study sought to examine the feasibility of primed picture-naming, specifically masked priming, with ERP recordings in typically speaking adults. Their stimuli included single-object, color images. Participants in this study named a total of 300 images or trials; 50 trials containing unrelated prime words, 50 trials containing target prime words (the picture's common name or label), and the other 200 were filler trials. No items were seen more than once. Each participant received a training session in which they viewed and named the stimulus pictures in black and white with the target name before and after the presentation of the picture. This was to familiarize the participants with the stimuli in order to increase naming agreement in the study. After the training, participants were fitted with a 32 channel electrode cap, and sat in a sound attenuated room with dimmed lighting to complete the study. For each trial of the study, a fixation cross was presented for 500 ms, followed by a 200 ms forward-patterned mask, a 70 ms prime word, a 50 ms backward mask, a 200 ms target picture, and then a blank screen for 1,000 ms before the next trial began. During instructions naming accuracy was stressed over quickness (Chauncey, et al., 2009).   Behaviorally, it was shown that pictures which were preceded by the target prime word were named significantly faster than the pictures preceded by the unrelated prime word (Chauncey, et al., 2009). The same effect was found for naming accuracy. ERP mean amplitude measurements were analyzed in three time windows or epochs: 200-300 ms, 300-500 ms, and 500-700 ms. ERP results showed that during all three time windows or epochs, a significantly more negative-going wave was seen when the prime word was an unrelated word rather than the target word. Distribution analyses found that there were significant anterior-posterior, laterality, epoch interactions. It is thought that the priming effects seen in the first time window (200-300 ms) reflect the pre-activation of structural features of the picture (Chauncey et al., 2009). The priming effects seen in the second window (300-500 ms) were attributed to activation of semantic information, and those in the third window (500-700 ms) were attributed to phonological and articulatory planning (Chauncey et al., 2009). The goal of this study was to determine the feasibility of using a primed picture naming methodology with ERPs, and this goal was accomplished based off of the statistically significant priming effects found during each of the three time windows. Though the conclusions made in this study are only tentative interpretations due to the novel methodology used, further research using this method can be implemented in order to study the underlying processes of speech production during picture naming; therefore, we chose to extend upon this research and apply the methodology used from this study to AWS.

Summary and Research Question

Stuttering affects over a million adults in the United States and can have a negative impact on their quality of life. Many speech-language pathologists have expressed a lack of confidence in treating stuttering, possibly due to unknowns in regards to etiology and effective treatment. Current models of stuttering integrate underlying influences such as, genetics and environment, speech production and planning, as well as exacerbating factors. There is strong evidence that there is an incoordination of the articulators and larynx during speech production of people who stutter, but the evidence behind language processing is not as well defined.

This leads us to the aim of our research, which is to extend our knowledge of language processing in AWS through the use of ERPs and a masked priming methodology.

Masked priming allowed us to investigate language processing in AWS, during, rather than immediately after picture naming by limiting task artifacts such as, delayed naming and working memory demands as seen in a picture-word naming paradigm. On each trial of the masked priming task, implemented by Chauncey et al. (2009), participants saw a masked prime word which was either the label of the picture or unrelated to the label of the picture, and named the picture as soon as it appeared on the computer screen. They found effects at three different time windows suggesting the following priming effects in each time window: 1) pre-activation of structural features of the picture 2) activation of the semantic features and 3) activation of phonological and articulatory planning. Using this masked picture priming paradigm, we sought to learn more about linguistic processing in AWS and expand upon the current research. The following questions are asked in our research: 1) Did we replicate the findings of Chauncey et al. (2009) in our TFA group? 2) Do the AWS show behavioral results similar to those of the TFA? and 3) Do AWS show similar ERP correlates of masked picture priming as compared to TFA. Based on previous work (Maxfield et al., 2010, 2012), the middle or late ERP components reported by Chauncey et al. (2009) were predicted to exhibit a different morphology in AWS versus TFA, indicative of atypical lexical selection or morphophonological-articulatory processing, respectively, in AWS.

Method

Participants

Participants gave written informed consent to participate, completed a medical and language history questionnaire, and were paid 20 U.S. dollars upon completion of the study. Participants were 19 AWS (6 female, mean age = 26 years, 1 month) and 19 TFA (5 female, mean age = 24 years, 10 months). The difference in age between groups (mean difference = 14.79 months) was not statistically significant ($t(36) = .724$, $p = .474$). All participants were monolingual speakers of English. All had normal or corrected-to-normal vision. Two TFA, and one AWS, were left-handed. No participants took medications that affect cognitive function, and all were neurologically healthy.

All participants minimally had a high school education or GED-equivalent. Eleven AWS had also completed some form of post-secondary education at time of testing, including trade school (n = 2), undergraduate college degree (n = 6), graduate college degree (n = 2) or doctorate (n = 1). Similarly, 10 TFA had at least some post-secondary education at time of testing, including a completed undergraduate college degree (n = 7) or graduate college degree (n = 3).

Participants in the AWS group self-reported a history of stuttering. Videotaped samples of both read and spontaneous speech were analyzed to confirm the presence of stuttering. Additionally, the impact of stuttering was assessed using the Overall Assessment of the Speaker's Experience with Stuttering (OASES) (Yaruss & Quesal, 2006). OASES scores averaged 46.96 (SD = 10.19). Overall impact ratings were distributed as follows: Mild (n = 1), Mild-to-Moderate (n = 7), Moderate (n = 10), and Severe (n = 1). Six of the 19 AWS reported a family history of stuttering. One AWS reported a family history of dyslexia, and another AWS reported a family history of learning difficulty (the reporting participants were, themselves, not affected by these conditions). A subset of AWS had a history of co-existing conditions, including mild articulation deficit (n = 2), mild attention deficit disorder (n = 1, untreated using medication), mild learning disability (n = 1), delayed speech (n = 2), and vocal nodules (n = 1).

All of the TFA, and all but one AWS, scored within normal limits on both the Peabody Picture Vocabulary Test-Fourth Edition (PPVT-4) and on the Expressive Vocabulary Test-Second Edition (EVT-2). One AWS had a standard score of 84 on the PPVT-4, indicative of slightly below-normal receptive vocabulary knowledge. As a group, the AWS scored lower than the TFA on both the PPVT-4 (AWS mean = 103.58, SD = 10.59; TFA mean = 111.32, SD = 11.81) ($t(36) = 2.13$, $p = .041$), and EVT-2 (AWS mean = 103.53, SD = 12.19; TFA mean = 114, SD = 13.78) ($t(36) = 2.48$, $p = .018$).

Stimuli

Stimuli were 300 black-line drawings of common objects, selected from the International Picture Naming Project (IPNP) (Szekely et al., 2004). The target picture label (i.e., the most frequently-used label) for each line drawing, according to IPNP norms, was a noun. Percent naming agreement for each picture in English, also normed as part of the IPN Project, was 84% or better (mean agreement = 95.4%, SD = 5.26). Target picture labels had no more than three syllables (mean = 1.52, SD = .62) and no more than eight letters (mean = 5.12, SD = 1.45).

Target labels of the 300 line drawings served as prime words. For each participant, 50 of the line drawings were randomly-assigned to the Identity priming condition, for which they were paired with a printed probe word identical to the target label. The remaining 250 line drawings were randomly assigned an unrelated prime word (i.e., each picture was randomly paired with a label from another remaining picture). Of those, 50 were randomly-selected as Control items, and the remaining 200 items were treated as Fillers. Each picture and prime word appeared just once during the experiment.

Procedure

Participants were told that on each trial they would see a picture preceded by a rapid letter scramble. Instructions were to pay attention to the letter scramble, and then name aloud the picture, emphasizing accuracy of naming over speed. Each trial comprised a crosshair fixation point displayed for 500 ms, followed by a pattern mask (########) displayed for 200 ms, after which a printed prime word was displayed for 70 ms, and then a backward mask comprised of eight different capitalized consonants for 50 ms, and finally a picture. The picture remained on-screen until naming triggered a voice key, at which time the picture was replaced by a blank screen for 900 ms, followed by instructions to "Press any button for the next trial" which remained on-screen until a push-button response was made. AWS were instructed to say the picture label on each trial completely if they encountered a moment of stuttering, before cueing-up the next trial.

Each participant received a total of 300 trials, presented in a single block lasting ~15 minutes in duration. The order of item presentation was completely randomized. Ten different eight-letter backward masks were used (RKMVDGJH, CZXNHGFV, BPHMNKRZ, DKXVTRWQ, TRFZGSQD, BZJPFCLM, MBGXSHQT, VNGQSFJK, LDSCNGQR, QTRMNPBK), each appearing 30 times with random selection.

Apparatus and Recording

Each participant sat in a sound-attenuating booth facing a 19-inch monitor. Maximum onscreen height and width of pictures measured 10.7 centimeters. Viewing distance was ~90 cm. The visual angle of the pictures subtended ~6.8 degrees. Eprime (Psychological Software Tools, Version 1.1) controlled the experiment and logged naming reaction times registered using a voice key (Psychological Software Tools).

Each participant wore a nylon QuikCap (Neuroscan) fitted with 32 active recording electrodes positioned according to the International 10-20 system (Klem et al., 1999).

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 (VEOG) electrodes, and two bipolar-referenced horizontal electro-oculograph (HEOG) electrodes, recorded electro-ocular activity. Electrodes were constructed of Ag/AgCl. EEG was recorded continuously at a sampling rate of 500 Hz, controlled using SCAN software, Version 4.3 (Neuroscan). Electrode impedance was 5 kOhm or less. Continuous EEG data were low-pass filtered online at a corner frequency of 100 Hz (time constant: DC).

EEG-to-Average ERP Data Reduction

The continuous EEG record of each participant 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 1000 ms after picture onset. Trials eliciting incorrect picture names were excluded. Filler trials were epoched and included in the processing sequence until averaging, primarily to ensure that an eye-blink correction algorithm would function as accurately as possible. In order to retain as many trials as possible (Picton et al., 2000), an Independent Component Analysis (ICA)-based (Bell & Sejnowski, 1995), ocular artifact correction procedure (Glass et al., 2004) was implemented in Matlab. After ICA blink correction, channels whose fast-average amplitude exceeded 200 microvolts (large drift) were marked bad, as were channels whose differential amplitude exceeded 100 microvolts (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. As a result, each participant had two sets of ERP averages (one for Identity, one for Control). No fewer than 40 trials went into the set of ERP averages for each condition. The averaged ERP data were low-pass filtered at a corner frequency of 40 Hz, baseline-corrected (-100 to 0 ms), re-referenced to left mastoid, and finally truncated to the critical time window (-100 to 800 ms).

Analysis

Behavioral data. Naming accuracy and reaction times (RTs) were both analyzed. Naming on each trial was correct if the participant used the target label. Naming was incorrect for trials eliciting no response, a whole-word substitution, a phonological error or a multi-word response. For the accuracy data, a repeated-measures analysis of variance (ANOVAs) was conducted with Condition entered as a within-subjects factor with two levels (Identity versus Control) and Group entered as a between-subjects factor with two levels (TFA versus AWS). Naming RTs were analyzed using this same approach. However, RTs were first trimmed to remove outliers. Trimming involved removing data points greater than one standard deviation from the mean, separately for each participant. This approach was chosen because subject variability was high in the RTs (for details, see Ratcliffe, 1993). Both statistical tests (naming accuracy and naming RT) were two-sided and had an alpha-level of 0.05.

ERP data. As in previous papers (Maxfield et al., 2010; 2012), ERPs were submitted to a covariance-based, two-step, sequential temporal-spatial principal component analysis (PCA) (Dien, 2010a) using Dien's Matlab-based PCA toolbox (2010b). The aim of the initial, temporal PCA was to identify distinct windows of time (hereafter, temporal factors) during which similar voltage variance was registered across consecutive sampling points in the average ERP waveforms. For this step, subject ERP averages were combined into a matrix comprised of 401 columns (one column per time point in the 0 to 800 ms epoch) and 2,356 rows (averaged ERP voltages for 38 participants, in each of two conditions, at each of 31 electrodes excluding the left mastoid reference electrode). Rule N (Preisendorfer, Zwiers & Barnett, 1981; Preisendorfer & Mobley, 1988), in combination with the Scree Test (Cattell, 1966), were used to determine how many dominant-variance temporal components to retain and rotate. Ten temporal factors were rotated to simple structure using Promax (Hendrickson & White, 1964) with Kaiser normalization and k=3. Each rotated temporal factor is defined by a set of loadings that, when variance-scaled, describe the time-course of each temporal factor, including its peak latency. Each temporal factor is also associated with a set of scores that describe the voltage variance during the window of time defined by the temporal factor. The scores were free to vary in amplitude as a function of condition, group and electrode location.

Next, temporal factors with peak latencies ranging from 300 to 700 ms after picture onset were targeted for further analysis. Each temporal factor will be referred to by its peak latency (e.g., T380). The two language production-related masked priming effects seen in Chauncey et al. (2009) occurred within this time range. The scores associated with each temporal factor were submitted to a spatial PCA in order to determine whether multiple, topographically distinct patterns of variance (hereafter, spatial factors) were active within the time window represented by each temporal factor. Similar to (Foti, Hajcak & Dien, 2009; Dien, Michelson & Franklin, 2010), we found that applying a separate spatial PCA to each set of temporal factor scores provided a more interpretable picture of the topographic variance distribution. Scores associated with each temporal factor were reconfigured into a matrix with 31 columns (one column per electrode excluding the left mastoid) and 76 rows (reflecting the ERP variance during the time window associated with that temporal factor, for each of 38 participants, in each condition). Each matrix was then submitted to a spatial PCA. Also following recommendations by (Dien, 2010a), retained spatial factors were rotated using an Infomax rotation (Bell & Sejnowski, 1995). Since Preisendorfer's Rule N (used for the Temporal PCA) poorly estimates the number of dominant-variance components in small-n data sets (Preisendorfer et al., 1981), North's rule of thumb (North, Bell, Cahalan & Moeng, 1982) was used to determine the maximum number of spatial factors that could be well-separated. North's rule gives an upper limit of the number of potentially meaningful factors. Each rotated spatial factor is defined, topographically, by a set of loadings that give the correlation of the spatial factor with the electrodes.

Filtering the averaged ERP activity by a temporal factor, and then by a spatial factor, isolates the ERP variance within the time window defined by the temporal factor, and at the scalp region defined by the spatial factor. The isolated variance is expressed in a set of temporal-spatial factor scores, one for each participant in each condition (the scores were variance-scaled but not mean-centered, so as to preserve their amplitude relative to baseline). In order to test for experimental effects, temporal-spatial factor pairs consistent with the time-course and scalp topography of relevant ERP components were analyzed. Each set of temporal-spatial factor scores was submitted to repeated-measures ANOVA, with Condition as a within-subjects factor having two levels (Identity priming versus Control) and Group as a between-subjects factor having two levels (TFA versus AWS). When a Group-by-Condition interaction was detected, pairwise t-tests were used to compare the scores for Identity priming versus Control, separately for each Group. All statistical tests were two-sided and had an alpha-level of 0.05. Only combinations associated with statistically significant effects are reported.

Results

Behavioral Data

Naming accuracy. Naming accuracy was high for both groups (Table 1). Accuracy was affected by Condition (F(1,36) = 11.31, p = .002), with Identity-primed trials more accurate than Controls (mean difference = 1.18). This suggests that processing of target picture labels was stabilized with Identity priming. Naming accuracy was not affected by Group (F(1,36) = .885, p = .353), or by the interaction of Group and Condition (F(1,36) = .453, p = .51).

Naming reaction time. Naming RTs (Table 1) were also affected by Condition (F(1,36) = 12.64, p = .001), with Identity-primed trials eliciting faster naming than Controls (mean difference = 50.96 milliseconds). This result again suggests that processing of target picture labels was facilitated by Identity priming. Naming RTs were also affected by Group (F(1,36) = 6.57, p = .015), with AWS slower than TFA (mean difference = 318.12 ms) regardless of Condition. Naming RT was not affected by the interaction of Group and Condition (F(1,36) = .06, p = .805).

ERP Data

Figures 2 and 3 show grand average waveforms for each condition at 14 electrodes, separately for each group. As shown in Figure 2, an overall pattern of ERP activity was elicited in the TFA. This included an early positivity, peaking at roughly 100 ms after picture onset, followed by negativity peaking at roughly 200 ms after picture onset, followed by another positivity peaking at roughly 400 ms after picture onset and, lastly, followed by later, slow-wave activity. Putative priming effects within the time range of interest (300-700 ms) can be seen at electrode CZ, starting at roughly 300 ms after stimulus onset. A widespread priming effect was also observed at a later latency at the majority of the electrodes. As noted in the Introduction, Chauncey et al. (2009) found two language-related ERP components, one with a peak latency between 300-500 ms (i.e., an N400-like priming effect) and another with a peak latency between 500-700 ms (their proposed measure of post-lexical processing).

As shown in Figure 3, an overall pattern of ERP activity was also elicited in the AWS, similar to that of the TFA. This, too, included an early positivity peaking at roughly 100 ms after picture onset, followed by negativity peaking at roughly 200 ms after picture onset, followed by another positivity peaking at roughly 400 ms after picture onset and lastly followed by later, slow-wave activity. Visual inspection did not reveal an obvious N400 effect at CZ, as seen in the TFA. Marginal signs of a later effect were seen, but with a less–widespread topographic distribution. Crucially, however, there was evidence of positive-going activity in the control condition that was not observed in the identity condition, peaking at roughly 300 ms after picture onset time. This effect was not observed in the TFA.

The putative priming effects, noted above, were confirmed using sequential, temporal-spatial PCA. Temporal PCA produced three temporal factors with peak latencies in the target time range (300-700 ms after picture onset). One had a peak latency at 380 ms after picture onset (T380), the second peaked at 516 ms (T516) and the third peaked at 624 ms (T624). After topographically-partitioning the variance associated with each temporal factor using spatial PCA, experimental effects were detected within the T380 and T516 time windows but not for T624.

T380 effects. T380 accounted for 1.67% of the variance in the grand average waveforms. The time-course of T380 is shown in Figure 4 (top right panel). The T380 variance was partitioned topographically by five Infomax-rotated spatial factors (accounting for 95.57% of the T380 variance), two of which were targeted for analysis. As shown in Figure 4 (top left panel), one spatial factor was defined primarily by central electrodes with polarity inversion at right lateral sites. The T380/central activity was modulated by an interaction of Condition and

Group (F(1,36) = 5.24, p = .028). Pairwise tests, comparing Identity priming versus Control for each group, revealed that for the TFA only, Control elicited a negativity relative to Identity priming (p = .006) (Figure 4, bottom and middle panels show this effect in the T380/central factor scores and in the TFA grand average at electrode Cz). The scalp topography and time-course of this effect are consistent with an N400-like component (Van Petten & Kutas, 1991; Kutas & Federmeier, 2011).

Since the AWS did not produce an N400-like priming effect, we questioned whether other ERP activity was modulated by Identity priming in AWS at the same general latency. Visual inspection of the grand average waveforms for AWS pointed to a putative, P300-like priming effect at ~380 ms after picture onset (see Figure 3, AWS, electrode Pz). Therefore, we targeted another spatial factor derived from T380, defined primarily by posterior electrodes. The T380/posterior activity was also modulated by an interaction of Condition and Group (F(1,36) = 6.84, p = .013). Pairwise tests, comparing Identity priming versus Control separately for each group, revealed that for the AWS only, both conditions elicited positive-going activity that was larger in amplitude for Control versus Identity priming (p = .015) (Figure 5, bottom and middle panels show this effect in the T380/posterior factor scores and in the AWS grand average at electrode Pz). The scalp topography and time-course of this effect are consistent with a P300-like component (Spencer, Dien & Donchin, 1999; 2001; Dien, Spencer & Donchin, 2004). P300 activations have been associated with attentional control during stimulus evaluation, while N400 activations have been associated with lexical-semantic processing (Kok, 2001).

T516 effects. T516 accounted for 36.33% of the variance in the grand average waveforms. The T516 time-course is shown in Figure 6 (top right panel). The T516 variance was partitioned topographically by five Infomax-rotated spatial factors (explaining 94.23% of the variance in the T516 factor scores). One spatial factor (Figure 6, top left panel) was defined by high loadings at posterior electrodes with inversion at anterior sites. The T516/posterior activity was modulated by Condition ($F(1,36) = 6.621$, $p = .014$), with Identity priming eliciting a positivity relative to Control (Figure 6, bottom and middle panels show this effect in the T516/posterior factor scores and in the grand average at electrode Oz). This effect is similar (in latency, polarity and, partially, in scalp topography) to the late priming effect reported by Chauncey et al. (2009), which they attributed to post-lexical processing of picture labels

Discussion

AWS and TFA spontaneously named pictures preceded by masked printed prime words. Primes were Identical to, or mismatched, target picture labels. In question was whether Identity priming modulated the amplitude of language production-related ERPs relative to mismatch (Control), similarly between groups.

Observed ERP Priming Effects

Different ERP components, peaking at ~400 ms after picture onset, responded to priming between groups. The TFA group produced a central negativity to Control that attenuated with Identity priming, consistent with an N400 priming effect. N400-like activity can be elicited by a range of tasks that require meaningful processing of stimuli (Kutas & Federmeier, 2011), and its amplitude varies inversely with the strength of activation that emerges from a priming context (Van Petten & Kutas, 1991). In tasks using local priming manipulations, N400 probably reflects rapid and automatic lexical-semantic processing (Van Petten, 1995). Based on these accounts, the N400 effect produced here by TFA is interpreted as reflecting the automatic spread of activation to lexical items as pictures were evaluated conceptually, punctuated by lexical selection, with this process facilitated by Identity priming.

In contrast, a P300 component responded to priming in the AWS group at the same latency (~400 ms after picture onset). In interpreting this effect, it is important to acknowledge that P300 activity can be sub-divided into two components, P3a and P3b. A fixed and defining feature of P3b is its posterior scalp topography (Spencer, Dien & Donchin, 2001), consistent with the effect generated by AWS. As summarized by Kok (2001), "P3b has been regarded as a sign of processes of memory access that are evoked by evaluation of stimuli in tasks that require some form of action like a covert or overt response" (Donchin, Kramer & Wickens, 1986)

(p. 557). Since P3b amplitude varies proportionally with the amount of attentional resources recruited during stimulus processing, but is affected little by processes involved in response selection or execution, Gray, Ambady, Lowenthal and Deldin (2004) characterized P3b as "...a covert measure of attention that arises largely independently of behavioral responding" (p. 217). More recently, Polich (2010) speculated that P300 activity arises "...from the initial need to enhance focal attention to isolate task-relevant contents of working memory during stimulus detection" (p. 25). Based on these accounts, the P3b effect seen here for AWS is interpreted as reflecting that attentional control (effortful, controlled processing) was heightened as pictures were evaluated, presumably with the aim of isolating target labels in working memory on the path to naming.

Maxfield et al. (2010) reported other, albeit less direct, ERP evidence pointing to the same conclusion. There, we used picture-word priming, as outlined in the Introduction. Crucially, AWS produced an atypical, reverse semantic N400 priming effect during probe word processing. That is, when the label of the preceding picture was semantically-related to the subsequent probe word, probe-elicited N400 activity was larger in amplitude than N400 to probes unrelated in meaning to their picture primes (rather than smaller in amplitude, the expected outcome demonstrated by a TFA control group). One interpretation was that, at picture presentation, the AWS engaged a center-surround inhibition mechanism aimed at stabilizing selection of the target picture label by inhibiting semantically-related neighbors. Center-surround inhibition is a compensatory attentional mechanism, proposed by Dagenbach, Carr and Barnhardt (1990), for retrieving words poorly-represented in the mental lexicon (e.g., newly-learned vocabulary words). As described by Carr and Dagenbach (1990), "...when activation from the sought-for code is in danger of being swamped or hidden by activation in other related codes, activation in the sought-for code is enhanced, and activation in related codes is dampened by the operation of the center-surround retrieval mechanism" (p. 343). In

Maxfield et al. (2010), the reverse semantic N400 priming effect, produced by AWS, was seen as a possible sign that this group had to reactivate (or, disinhibit) semantic neighbors after they had just, presumably, been inhibited by a center-surround mechanism (for similar results in TFA see Mari-Beffa, Valdes, Cullen, Catena & Houghton, 2005; Bertmeitinger, Frings, & Ventura, 2008). However, that conclusion was speculative without direct evidence of processing time-locked to picture onset. The current results provide evidence that, in AWS, attentional control is heightened during picture processing in the absence of Identity priming, pointing to effortful, controlled processing during lexical selection.

There are at least three different reasons why enhanced attentional control during lexical selection might be necessary in AWS. First, it is possible that target words activate unstably on the path to naming due to diminished or atypical semantic connections in the mental lexicons of AWS. Evidence for this has been reported in previous work (reviewed in Maxfield et al., 2010, 2012) and was seen here, too, in low-normal receptive and expressive vocabulary scores for AWS (see Method). A second possibility is that there are insufficient attentional resources to support lexical selection in AWS, resulting in unstable activation of target words on the path to naming. Ferreira and Pashler (2002) showed that initial stages of picture naming (concept formation, lexical selection) are subserved by domain-general attentional resources. There is evidence that attentional resources are allocated away from lexical-semantic processing in AWS which may reflect a strategy for managing fluency (Bosshardt, 2006), or aberrant resource allocation (Arends, Povel & Kolk, 1988; Heitmann, Asbjornsen, & Helland, 2004; also see Bajaj, 2007). A third possibility is that, instead of target words activating unstably in AWS, their semantic neighbors become too strongly activated. AWS often use linguistic devices (e.g., word substitutions, circumlocutions) to limit stuttering. Such strategies may become automatized over time, perhaps resulting in a stampede-like activation of semantically-relevant words in the mental lexicons of AWS on the path to naming, included among them the target. In any of the three scenarios considered here, an extra "boost" may be needed to select the target word. A reasonable compensatory strategy would be for AWS to sharpen their focal attention in order to isolate the target word from semantic competitors. This is a plausible explanation for why AWS evidenced P300 activity on Control trials. With Identity priming, P300 activity was diminished in AWS, presumably because priming the target label immediately preceding picture onset helped it accrue a level of activation strength sufficient to facilitate selection without additional, effortful control.

Finally, a late Identity priming effect found here generalized to both groups. This effect had a posterior scalp distribution and a peak latency at ~516 ms after picture onset. Chauncey et al. (2009) attributed a similar effect to post-lexical processing. Borrowing on their interpretation, the generalized T516 effect here suggests that morphophonological and/or articulatory processing was similar in both groups on the path to naming. This conflicts with results from our most recent investigation using a picture-word priming paradigm (Maxfield et al., 2012), in which AWS evidenced an atypical, reverse Phonological N400 priming effect. That is, when probe words were phonologically-related to target labels of their picture primes, probe-elicited N400 activity was larger than N400 activity elicited by probe words unrelated to the labels of their preceding pictures (versus a typical phonological N400 priming effect observed for a TFA group). This led to speculation that AWS may also direct center-surround inhibition at phonological neighbors of target picture labels on-route to naming, in line with other previous work suggesting that AWS are slow to activate phonological constituents of target words, and slow to resolve competition between target words and their phonological neighbors (see Maxfield et al., 2012; for a related discussion see Tan & Perfetti, 1999). At the same time, we suspected that the task design used in (Maxfield et al., 2012) placed unusual demands on phonological processing and monitoring, in a manner not typical of spontaneous speech production, contributing to the reverse Phonological N400 effect seen there for AWS (i.e., that result may have been a task artifact; see Byrd et al., 2012 and Jones et al., 2012 for related discussions). This was, in part, the impetus for the current experiment. Although the T516 effect observed here points to stable post-lexical processing in both groups in spontaneous naming, the AWS did produce longer naming RTs than TFA. One speculation is that longer naming RTs reflect a downstream strategy or deficit in performance, consistent with a long line of evidence, mentioned previously, of speech motor control decrements in AWS.

Clinical Implications

As discussed above, enhanced attentional control during lexical selection may be necessary in AWS due to at least three different reasons. This leads us to propose several treatment and diagnostic clinical implications.

Lexical-semantic enrichment. First, with the possibility that AWS have diminished or atypical semantic connections in their mental lexicons, treatment to address this issue could include semantic network therapy and word knowledge enrichment in order to strengthen their mental lexicons and more specifically, their semantic connections. A body of research has suggested that AWS have atypical mental lexicons, but research involving more precise, online measurements is needed to better understand where the breakdown is occurring (reviewed in Introduction and Maxfield et al., 2010, 2012).

Another clinical population that have diminished mental lexicons are people with aphasia. Maher & Raymer (2004) address the management of word retrieval difficulty, anomia, which is a commonly occurring symptom of people with aphasia. Just as it is important to understand where there may be a breakdown in linguistic processing in AWS, the same is true with understanding the phenomenon of anomia. Word retrieval performance in people with anomia can be affected by factors such as a word's semantic category, word length, familiarity and frequency of occurrence. Factors similar to these have also been explored in AWS (see Au-Yueng & Howell, 1998 and Newman & Ratner, 2007). Though we have acknowledged that anomia and the linguistic deficits seen in AWS are not analogous, it is interesting to consider providing treatments similar to those provided to people with aphasia to AWS. There are many treatments to address anomia in people with aphasia, but one that specifically focusses on the semantic level is Semantic Feature Analysis Training (SFA). This treatment explicitly targets the strengthening of semantic representations through having clients produce a target label for a picture, given semantic features associated with the picture. SFA, in theory, would strengthen the connections between the semantic representations and the target lemma, as well as strengthen the semantic representations themselves (see Boyle, 2001; Boyle & Coehlo, 1995, and Coehlo, McHugh, & Boyle, 2000). It may also be beneficial to train with words that are atypical for the speaker in order to have a greater impact on the system (Kiran &Thompson, 2008, and Kiran 2008).

As previously mentioned, participants in this study had overall lower EVT scores, which could be further evidence for diminished or atypical semantic connections in their mental lexicons. Diagnostically, clinicians may want to 1) always perform language testing with their clients who stutter and 2) interpret the results of this language testing differently. For example, the EVT is a standardized language measure which compares a person's score to that of a normed sample of people with typical linguistic processing. Although comparing a person who stutters language testing scores to a typically fluent population may provide beneficial information, it would also be beneficial to compare their language testing scores to a group of people who stutter. If linguistic processing is in fact different in AWS, then comparing AWS to a normative sample of other AWS would allow clinicians to 1) get a more accurate picture of their language abilities and 2) plan more individualized treatment to enhance semantic connections and linguistic processing. It is important to understand that this diagnostic implication is only relevant given the interpretation that AWS do not have disordered linguistic processing, but atypical or different linguistic processing. Watkins (1997) explored language deficits in children who stutter (CWS) and did not find differences between children who stuttered and recovered, versus children whose stuttering persisted; however, he noted that it would be worthwhile to monitor the language production in CWS since language deficits have been seen in AWS. Monitoring the language of a child who stutters into adulthood could provide significant information about if or when language deficits begin to present themselves in people who stutter.

Attentional enhancement. Next, the idea that people who stutter have limited attention, suggests that therapy focusing on enhancing their attentional resources could be beneficial. Researchers have used a dual-task paradigm in order to study the attentional resources of AWS (Bosshardt, Ballmer & Nill, 2002; Jones et al., 2012). Bosshardt et al. (2002) and Jones et al. (2012) suggested that AWS require more processing capacity for speech production and that consequently their phonological and cognitive processing systems are more vulnerable to disruptions from dual attention-demanding semantic tasks as compared to TFA. Oomen & Postma (2001) explored how limitations in attentional resources affected pauses and repetitions in the speech of TFA using a dual-task paradigm and found that TFA had more disfluencies when speaking during a concurrent task. These studies allow us to speculate that AWS have more difficulty speaking fluently when their attention is divided between two tasks, which is a common task of daily living (i.e. driving while speaking on the telephone).

Similar results have been found using a dual-task paradigm with people with mild aphasia. Murray, Holland, & Beeson (1998) suggested that people with mild aphasia showed interference during divided-attention conditions due to decrements of attentional capacity and that this negatively affects their spoken language. However, Murray (2012) speculated that the attention abilities of people with aphasia are relatively intact, but that their limited language and communication abilities impede their performance on attention tasks. This is an interesting idea to consider with AWS. Perhaps their attentional abilities are not necessarily limited, but not as efficient as TFA due to their increased language demands. Attention Process Training (APT) has been used with people with cognitive impairments, traumatic brain injury, and aphasia in order to address attentional deficits and may be useful for AWS. APT "…consists of a group of hierarchically organized tasks that exercise different components of attention commonly impaired after brain injury including sustained, selective, alternating, and divided attention" (Sohlberg, McLaughlin Pavese, Heidrich, & Posner, 2000, p. 658). For example, patients in this type of therapy may complete tasks such as, "…alphabetizing words in an orally presented sentence, detecting targets with the presence of distracter noise or complex semantic categorization task requiring switching sets" (Sohlberg et al., 2000, p. 658). Sohlberg et al. (2000) reported that TBI patients often have difficulty with allocation of their attentional resources and switching between tasks that require different cognitive demands. After APT they reported seeing improvements in tasks not only involving attention control, but executive functioning (see also Murray, Keeton, & Karcher, 2006, and Pero, Incoccia, Caracciolo, Zoccolotti, & Formisano, 2006).

Speech-language pathologists can play a critical role in assisting AWS in use training programs such as APT to address executive function and attentional control skills. Methods similar to APT have also shown improvement in attention in people with mild cognitive impairment (see Rabipour & Raz, 2012). For example, Herrera, Chambon, Michel, Paban, & Alescio-Lautier (2012) reported improvement when using a computer based program to train tasks focusing on divided attention, visual focused attention, and visiospatial focused attention. Eggers, De Nil, & Van den Bergh (2012) conducted a study where CWS participated in the computerized Attention Network Test. They found that CWS had significantly lower efficiency of the orienting network, which has a role in allocating attentional resources, compared to children who do not stutter. This conclusion was made based off of a visual-spatial orienting task where CWS were less able to select information from sensory input. Implementing attentional control training in CWS could be beneficial due to their increased neural and behavioral plasticity (see Wass, Scerif, & Johnson, 2012).

Another novel treatment that could improve the efficiency of attention in AWS is musical training. First, musical training is multimodal and therefore, "…leads to more effective and faster learning than unimodal training (Lappe, Trainor, Herholz, & Pantev, 2011). Pairing musical training with more traditional approaches to fluency treatment (i.e. stuttering modification) could enhance learning and cognitive abilities such as allocation of attentional resources. Research has found associations between musical abilities and specific cognitive abilities, such as verbal or language abilities, and therefore, concluded that specific cognitive correlates are enhanced with musical abilities (Chan et al., 1998; Francois, Tillmann, & Schon, 2012; Rauscher et al., 1997; Rauscher & Zupan, 2000). Hanna-Pladdy & MacKay (2011) investigated the association between musical instrument participation and cognitive aging and found that those participants who were high activity musicians (10 plus years of experience) performed better in nonverbal memory, naming and executive function processes than non-musicians. Much of the research conducted to investigate the correlation between musical training and cognition has used a speech-in-noise paradigm and have found that children and adults who have had musical training demonstrated enhanced speech-in-noise perception suggesting that they have strengthened cognitive abilities (see Parbery-Clark et al, 2009 and 2011; Strait, Parbery-Clark, Hittner, & Kraus 2012).

Diagnostically, Ezrati-Vinacour & Levin (2001) proposed the idea that time-estimation could be a useful clinical tool in AWS to 1) exam their mental workload and 2) as an evaluation index to subjectively measure the difficulty of a situation. They found that AWS were less accurate than TFA at estimating time for oral and verbal tasks. This was attributed to conversation not being as automatic for AWS as it is for TFA and having more difficulty tracking time due to repetitions and pauses. It was discussed that AWS are frequently estimating the time of oral tasks, while speaking; therefore, this causes them to divide their attention between speaking and thinking about the timing of their speaking. For example, AWS may worry about taking up other people's time during conversation.

Reduction of verbal accessories. Lastly, AWS typically have a history of misusing their lexicon through avoidance behaviors such as, switching words, circumlocution, etc. Due to these habits, AWS often hold multiple words in mind when speaking in order to be prepared to switch their words to ones that they have less difficulty saying. Clinicians should assist AWS in reducing the use of these linguistic tricks, which is often part of stuttering modification therapy. Breaking this habit would eliminate the need for AWS to allocate cognitive resources to paying attention to which word they will choose. For a TFA, paying extra attention to each word they use would only occur in specific contexts, like a job interview; however, for AWS monitoring their word use is an avoidance behavior and becomes a habit. It is challenging for AWS to eliminate these linguistic tricks not only because they become second nature to them, but because AWS often perceive the stress level of "daily hassles" in a different manner than TFA (Blood, Blood, Bennett, Simpson, & Susman, 1994). AWS have shown significant differences physiologically and communicatively during stressful cognitive tasks as compared to TFA (Caruso, Chodzko-Zajko, Bidinger, & Sommers, 1994); therefore, reducing stress level in AWS may be necessary to aid in eliminating linguistic avoidance behaviors. Confronting linguistic avoidance behaviors could also be implemented through treatment focusing on pragmatics. For example, the clinician and client could role play common speaking situations and analyze appropriate vocabulary and frequently used expressions that go with given situations.

Summary and Conclusions

To summarize, the current results point to an increase in attentional control in AWS during lexical selection, presumably to stabilize activation of target lexical items. Three different proposals for why target words may activate unstably provide several directions for future research with AWS. Another question for future research is how a deficit in conceptual-to-lexical activation coupled with compensatory attentional control might affect speech motor control and fluency – particularly in connected speech? Still another question is whether the processing effects seen here are present in children who stutter, or whether they manifest as a result of experience with persistent stuttering into adulthood? In general, this study demonstrates the utility of using a neurophysiological approach to pinpoint differences in language and cognitive processes in speech production in AWS versus TFA. Results support the idea that language processes, and/or cognitive systems sub-serving them, operate differently in AWS and may need to be addressed in interventions for adulthood stuttering. First, with the idea that AWS have diminished or atypical semantic connections in their mental lexicon, treatment could be modeled after interventions used for people with aphasia (e.g., SFA) in order to strengthen semantic connections. Next, attentional enhancement may be an important intervention for AWS due to limitations in their attentional resources. Programs like APT, which exercises different components of attention, and musical training, which has been shown to enhance learning and cognitive abilities, could be used to address enhancing attention in AWS. Lastly, AWS typically have a history of misusing their lexicons through years of linguistic avoidance behaviors, such as switching their words. To address this, intervention could focus on 1) eliminating these linguistic tricks and 2) reducing stress in every day communication situations.

Table 1. Behavioral Data.

Group	Condition	Naming Accuracy (of 50 items)		Naming RT (ms)	
		Mean	*SD*	*Mean*	*SD*
TFA	*Identity*	48.05	1.22	973.86	222.49
	Control	47.11	2.18	1028.39	196.85
AWS	*Identity*	47.89	1.66	1295.54	519.22
	Control	46.47	1.54	1342.94	484.87

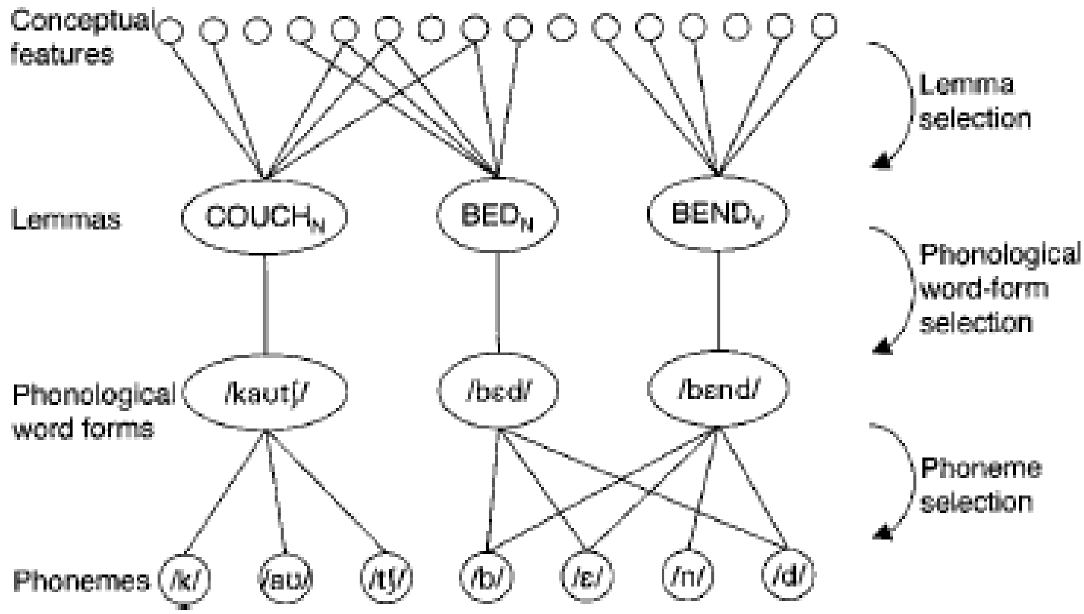

Figure 1. A network model of the mental lexicon (adopted from Ferreira & Pashler, 2002).

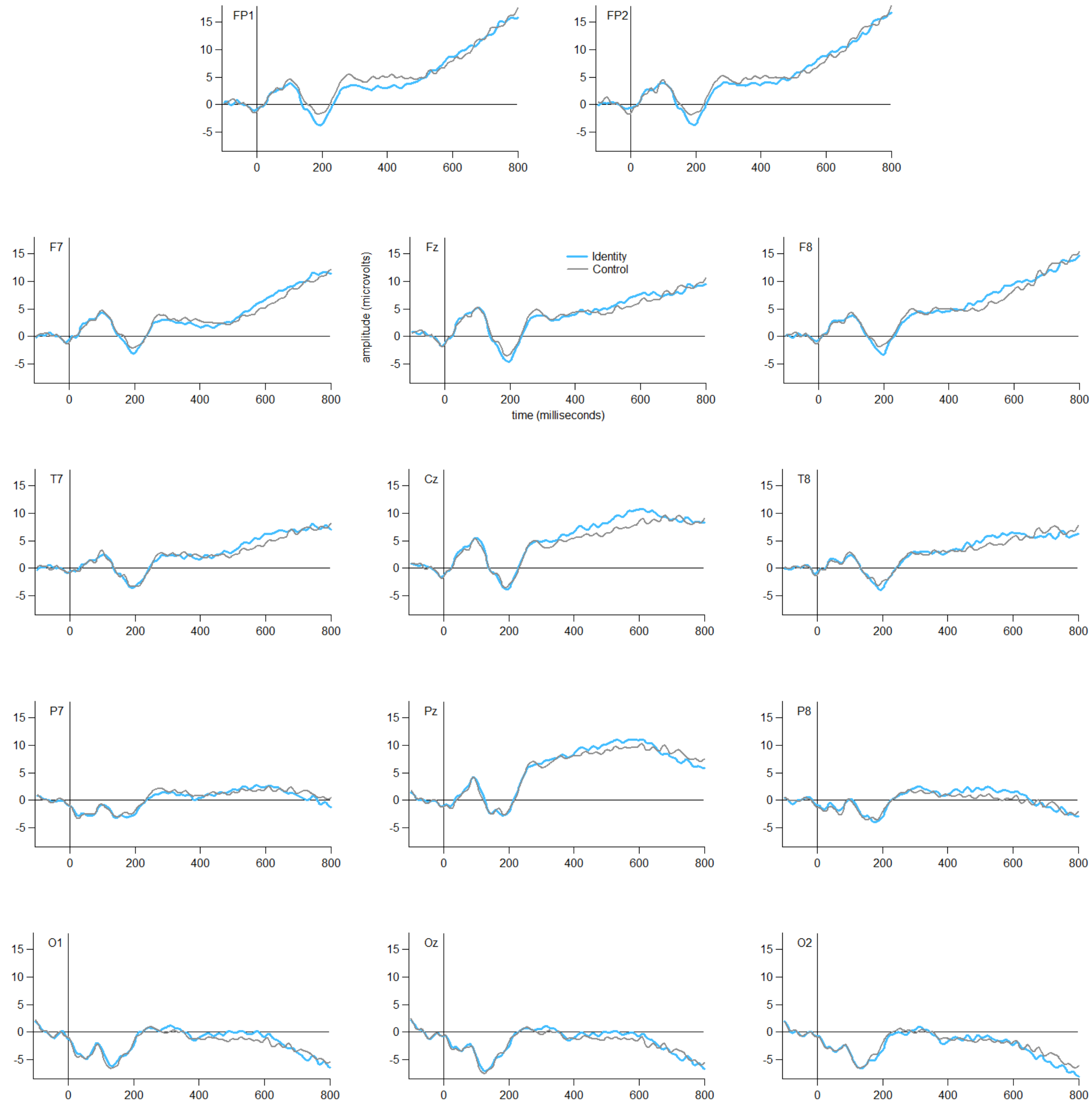

Figure 2. Grand average ERP waveforms for TFA at fourteen midline electrodes in each condition.

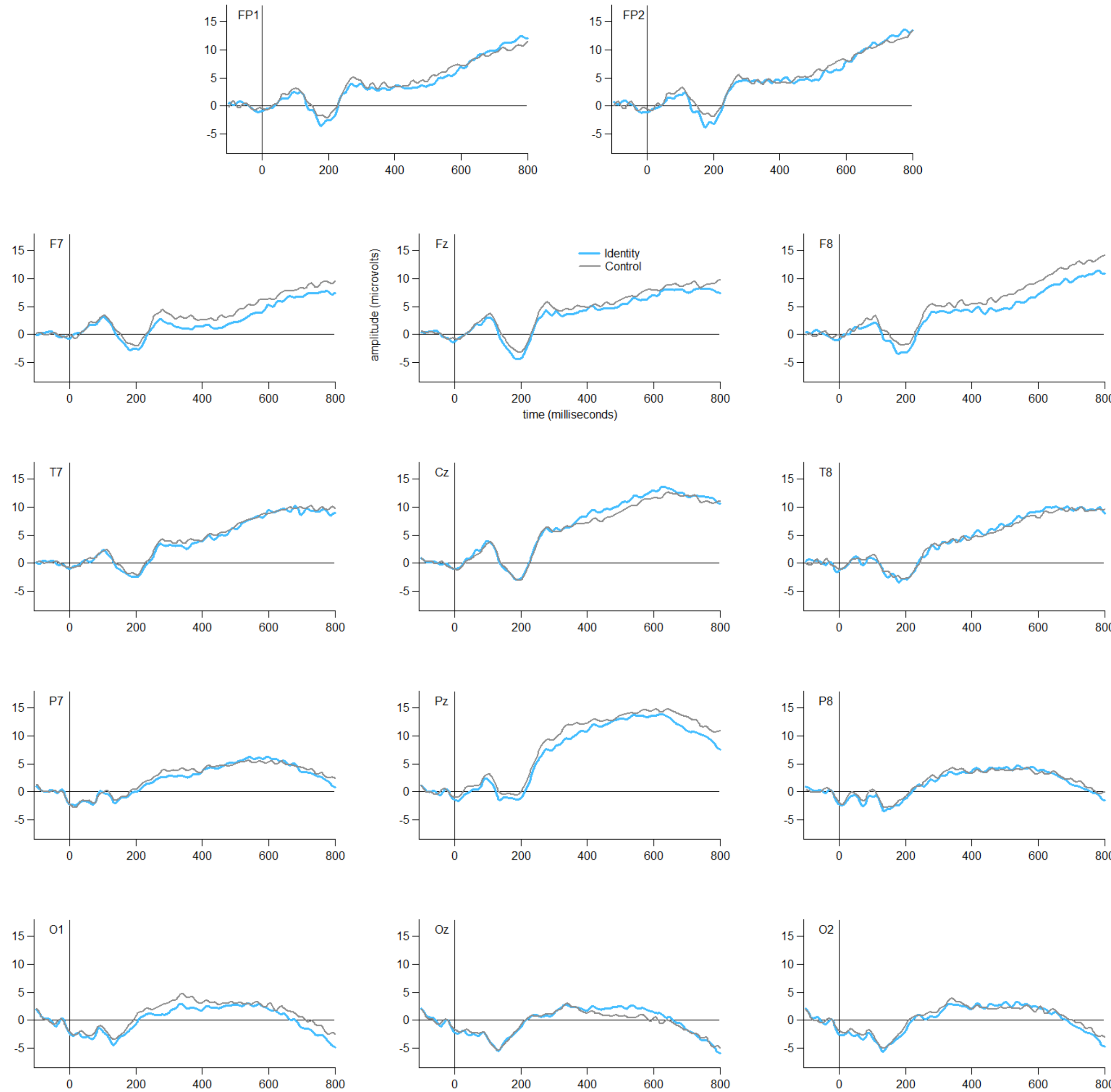

Figure 3. Grand average ERP waveforms for AWS at fourteen midline electrodes in each condition.

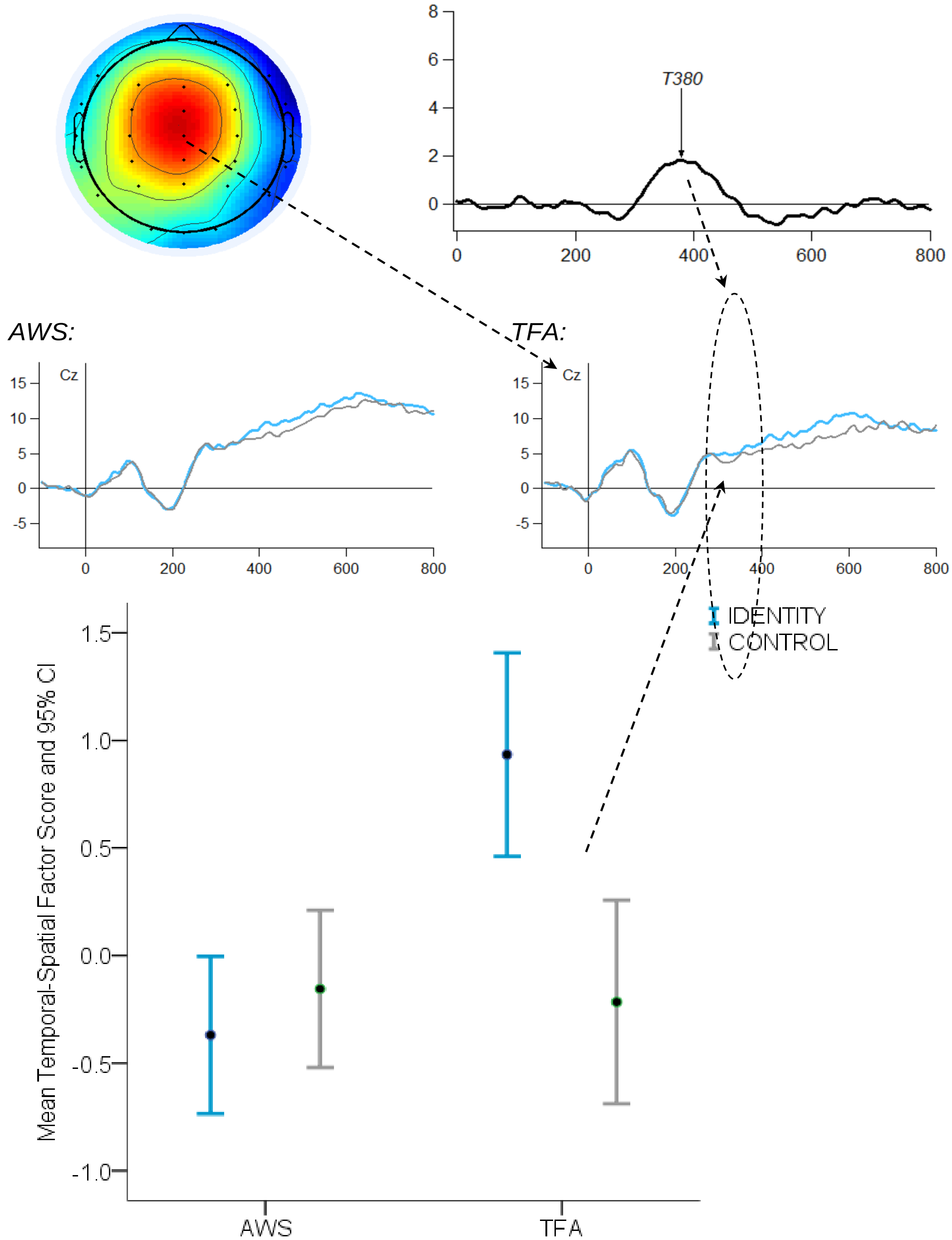

Figure 4. Factor loadings for T380 (top right). Topographic map of the central spatial factor associated with T380 (top left). Factor scores summarizing the ERP variance within the T380 time window at this scalp region (bottom). Illustration of this component activity in the TFA grand average waveform at electrode Cz (middle).

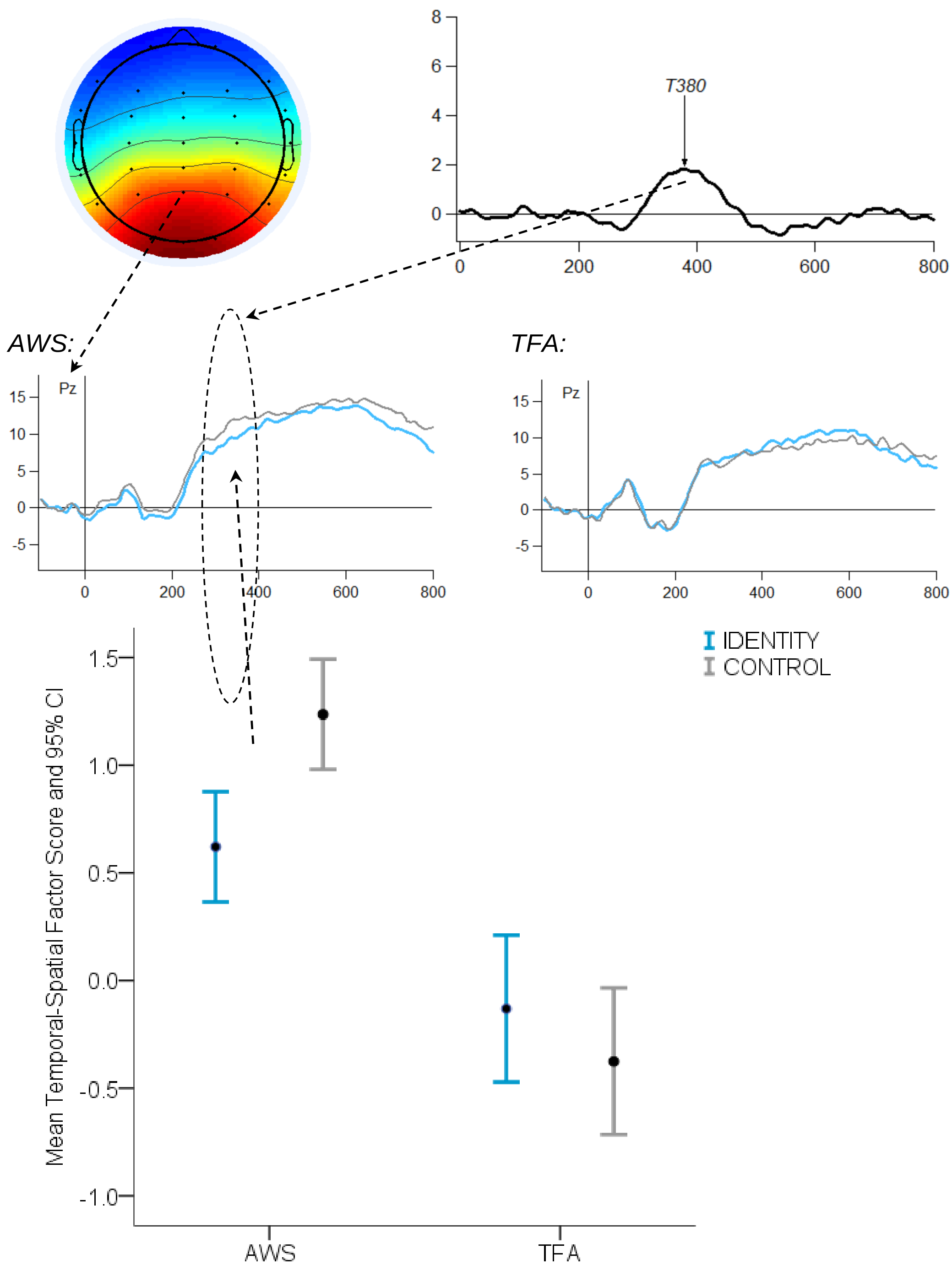

Figure 5. Factor loadings for T380 (top right). Topographic map of the posterior spatial factor associated with T380 (top left). Factor scores summarizing the ERP variance within the T380 time window at this scalp region (bottom). Illustration of this component activity in the AWS grand average waveform at electrode Pz (middle).

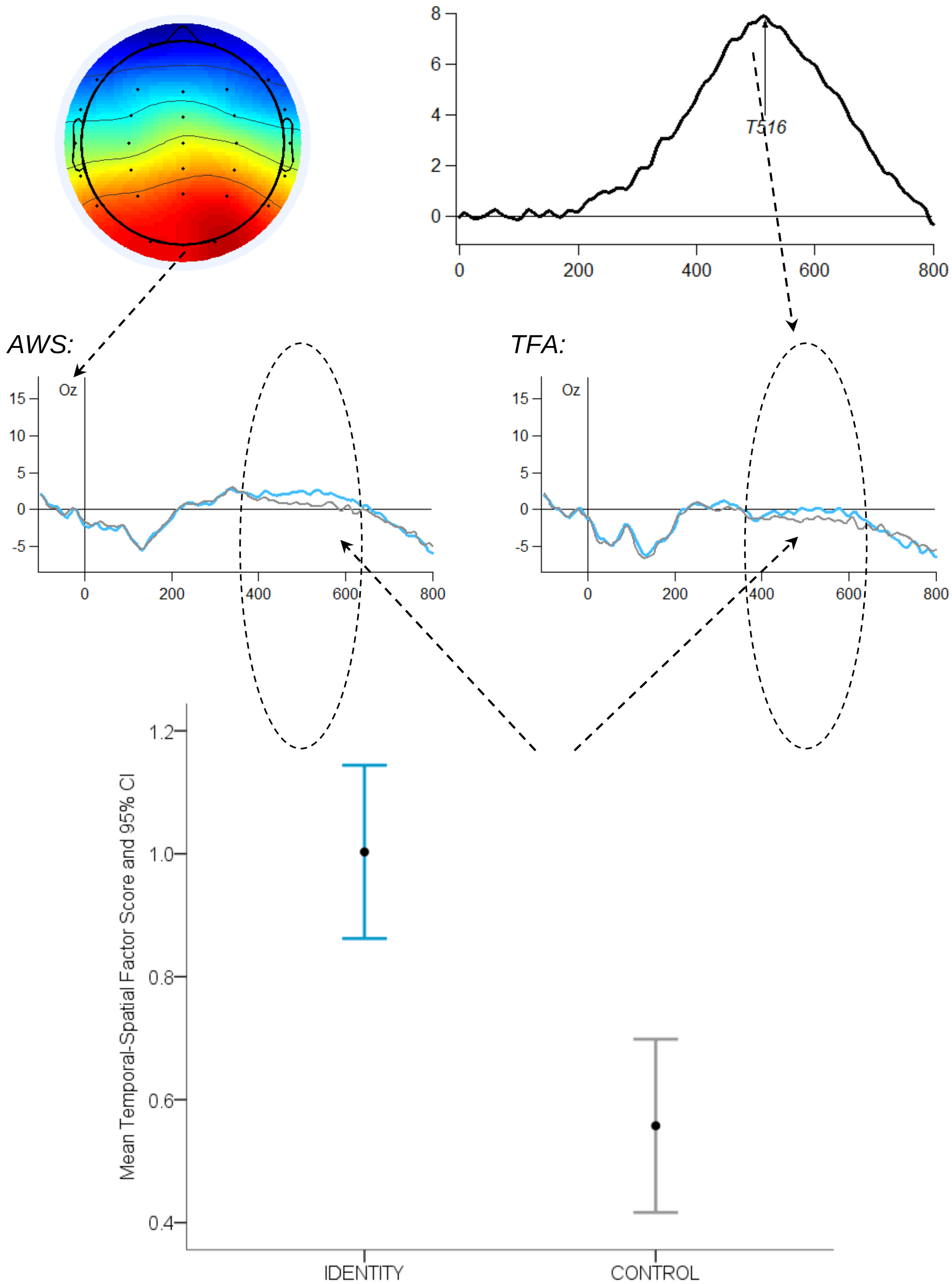

Figure 6. Factor loadings for T516 (top right). Topographic map of the posterior spatial factor associated with T516 (top left). Factor scores summarizing the ERP variance within the T516 time window at this scalp region (bottom). Illustration of this component activity in the grand average waveform at electrode Oz (middle).

References

Arends, N., Povel, D. J., & Kolk, H. (1988). Stuttering as an attentional control phenomenon. *Journal of Fluency Disorders, 13,* 141–51.

Au-Yueng, J., Howell, P., & Pilgrim, L. (1998). Phonological words and stuttering on function words. *Journal of Speech, Language, and Hearing Research, 41,* 1019-1030.

Bajaj, A. (2007). Working memory involvement in stuttering: exploring the evidence and research implications. *Journal of Fluency Disorders, 32(3),* 218–38.

Bell, A. J., & Sejnowski, T. J. (1995). An information maximization approach to blind separation and blind deconvolution. *Neural Computation, 7,* 1129–59.

Bermeitinger, C., Frings, C., & Wentura, D. (2008). Reversing the N400: event-related potentials of a negative semantic priming effect. *NeuroReport, 19(15),* 1479–582.

Blood, G. W., Blood, I. M., Bennett, S., Simpson, K. C., & Susman, E. J. (1994). Subjective anxiety measurements and cortisol responses in adults who stutter. *Journal of Speech, Language, and Hearing Research, 37,* 760-768.

Bloodstein, O., & Bernstein Ratner, N. (2008). *A handbook on stuttering*. Clifton Park, NY: Delmar.

Blumgart, E., Tran, Y., & Craig, A. (2010). Social anxiety disorder in adults who stutter. *Depression and Anxiety, 27,* 687-692.

Bosshardt, H. (2006). Cognitive processing load as a determinant of stuttering: summary of a research programme. *Clinical Linguistics & Phonetics, 20,* 371–85.

Bosshardt, H., Ballmer, W., & De Nil, L. F. (2002). Effects of category and rhyme decisions on sentence production. *Journal of Speech, Language, and Hearing Research, 45,* 844-857.

Bosshardt, H., & Fransen, H. (1996). Online sentence processing in adults who stutter and adults who do not stutter. *Journal of Speech, Language, and Hearing Research, 39,* 785-797.

Bosshardt, H., & Nandyal, I. (1988). Reading rates of stutterers and nonstutterers during silent and oral reading. *Journal of Speech and Hearing Disorders, 13*, 407–420.

Boyle, M. (2001). Semantic feature analysis: The evidence for treating lexical impairments in aphasia. In: *ASHA Division 2: Neurophysiology & Neurogenic Speech and Language Disorders Newsletter, 11,* 23-28.

Boyle, M., & Coehlo, C. A., (1995). Application of semantic feature analysis as a treatment for aphasic dysnomia. *American Journal of Speech Language Pathology, 4,* 94-98.

Brocklehurst, P. H., & Corley, M. (2011). Investigating the inner speech of people who stutter: Evidence for (and against) the covert repair hypothesis. *Journal of Communication Disorders, 44*, 246-260.

Burger, R., & Wijnen, F. (1999). Phonological encoding and word stress in stuttering and nonstuttering subjects. *Journal of Fluency Disorders, 24*, 91-106.

Byrd, C. T., Vallely, M., Anderson, J. D., Sussman, H. (2012). Nonword repetition and phoneme elision in adults who do and do not stutter. *Journal of Fluency Disorders, 37*, 188-201.

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology, 14,* 177-208.

Carr, T. H. & Dagenbach, D. (1990). Semantic priming and repetition priming from masked words: evidence for a center-surround attentional mechanism in perceptual recognition. *Journal of Experimental Psychology: Learning, Memory & Cognition, 16,* 341–50.

Caruso, A. J., Chodzko-Zajko, W. J., Bidinger, D. A., & Sommers, R. K. (1994). Adults who stutter: Responses to cognitive stress. *Journal of Speech and Hearing Research, 37,* 746-754.

Cattell, R. B. (1966). The scree test for the number of factors. *Multivariate Behavioral Research, 1,* 245–276.

Chan, A. S., Ho, Y. C., & Cheung, M. C. (1998). Music training improves verbal memory. *Journal of Nature, 396,* 128.

Chauncey, K., Holcomb, P., & Grainger, J. (2009). Primed picture naming within and across languages: an ERP investigation. *Cognitive, Affective, & Behavioral Neuroscience, 9*, 286-303.

Coehlo, C. A., McHugh, R., & Boyle, M. (2000). Semantic feature analysis as a treatment for aphasic dysnomia: a replication. *Journal of Aphasiology, 14,* 133-142.

Conture, E. G., Walden, T. A., Arnold, H. S., Graham, C. G., Hartfield, K. N., & Karrass, J. (2006). A communication-emotional model of stuttering. In N. Berstein Ratner & J. Tetnowski (Eds.). *Current issues in stuttering research and practice* (pp. 17-43). Mahwah, NJ: Lawrence Erlbaum Associates.

Cooper, E. B., & Cooper, C. S. (1996). Clinician attitudes towards stuttering: two decades of change. *Journal of Fluency Disorders, 21,* 119-135.

Craig, A., Blumgart, E., & Tran, Y. (2009). The impact of stuttering on the quality of life in adults who stutter. *Journal of Fluency Disorders, 34,* 61-71.

Craig, A., Hancock, K., Tran, Y., Craig, M., & Peters, K. (2002). Epidemiology of stuttering in the community across the entire life span. *Journal of Speech, Language, and Hearing Research*, *45,* 1097-1105.

Crowe, K. M., & Kroll, R. M. (1991). Response latency and response class for stutterers and nonstutterers as measured by a word-associated task. *Journal of Fluency Disorders, 16*, 35-54.

Cutting, J. C., & Ferreira, V. S. (1999). Semantic and phonological information flow in the production lexicon. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 318-344.

Dagenbach, D., Carr, T. H., & Barnhardt, T. M. (1990). Inhibitory semantic priming of lexical decisions due to failure to retrieve weakly activated codes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 328-340.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93,* 283-321.

Dell, G. S., & O'Seaghdha, P. G. (1992). Stages of lexical access in language production. *Cognition, 42,* 287-314.

Dien, J. (2010a). Evaluating two-step PCA of ERP data with Geomin, Infomax, Oblimin, Promax and Varimax rotations. *Psychophysiology, 47,* 170-183.

Dien, J. (2010b). The ERP PCA Toolkit: an open source program for advanced statistical analysis of event-related potential data (available from http://homepage.mac.com/jdien07/). *Journal of Neuroscience Methods, 157,* 138–45.

Dien, J., Michelson, C. A. & Franklin, M. S. (2010). Separating the visual sentence N400 effect from the P400 sequential expectancy effect: Cognitive and neuroanatomical implications. *Brain Research, 1355*, 126–140.

Dien, J., Spencer, K.S., Donchin, E. (2004). Parsing the ‘‘Late Positive Complex”: Mental chronometry and the ERP components that inhabit the neighborhood of the P300. *Psychophysiology, 41*, 665–78.

Donchin, E., Kramer, A., & Wickens, C. (1986). Applications of event-related brain potentials to problems in engineering psychology. In M.G.H. Coles, E. Donchin, & S. Porges (Eds.), *Psychophysiology: Systems, Processes, and Applications* (pp 557). New York: Guilford Press.

Eggers, K., De Nil, L. F., & Van den Bergh, B. R. H. (2012). The efficiency of attentional networks in children who stutter. *Journal of Speech, Language, and Hearing Research, 55,* 946-959.

Eldridge, K. A., & Felsenfield, S. (1998). Differentiating mild and recovered stutterers from nonstutterers. *Journal of Fluency Disorders, 23*, 173-195.

Ezrati-Vinacour, R., & Levin, I. (2001). Time estimation by adults who stutter. *Journal of Speech, Language, and Hearing Research, 44,* 144-155.

Ferreira, V. S., & Pashler, H. (2002). Central bottleneck influences on the processing stages of word production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 1187-1199.

Fischler, I. R. (1990). Comprehending language with event-related potentials. In J. Rohrbaugh, R. Parasuraman & R. Johnson (Eds.). *Event-related brain potentials: Basic issues and applications* (pp. 165-177). New York, NY: Oxford University Press.

Francois, C., Tilmann, B., & Schon, D. (2012). Cognitive and methodological considerations on the effects of musical expertise on speech segmentation. *Annals of the New York Academy of Sciences, 1252,* 108-115.

Glass, K., Frishkoff, G. A., Frank, R. M., Davey, C., Dien, J. & Maloney, A.D. (2004). A framework for evaluating ICA methods of artifact removal from multichannel EEG. In: ICA 2004, LNCS 3195. Berlin, Heidelberg: Springer-Verlag; p.1033–40.

Gray, H. M., Ambady, N., Lowenthal, W. T. & Deldin, P. (2004). P300 as an index of attention to self-relevant stimuli. *Journal of Experimental Social Psychology, 40,* 216-224.

Hagoort, P., & Kutas, M. (1995) Electrophysiological insights into language deficits. In F. Boller and J. Grafman (Eds.), *Handbook of Neuropsychology, Vol. 10.* Amsterdam: Elsevier Science Publishers B. V.

Hanna-Pladdy, B., & MacKay, A. (2011). The relation between instrumental musical activity and cognitive aging. *Journal of Neuropsychology, 25,* 378-386.

Heitmann, R., Asbjørnsen, A. & Helland, T. (2004). Attentional functions in speech fluency disorders. *Logopedics, Phoniatrics, Vocology, 29,* 119–27.

Hendrickson, A. E., & White, P. O. (1964). Promax: A quick method for rotation to oblique simple structure. *The British Journal of Statistical Psychology, 17,* 65-70.

Hennessey, N., Nang, C., Beilby, J. (2008). Speeded verbal responding in adults who stutter: Are there deficits in linguistic encoding? *Journal of Fluency Disorders, 33*, 180-202.

Herrera, C., Chambon, C., Michel, B. F., Paban, V., & Alescio-Lautier, B. (2012). Positive effects of computer-based cognitive training in adults with mild cognitive impairment. *Journal of Neurosychologia, 50,* 1871-1881.

Hubbard, C., & Prins, D. (1994). Word familiarity, syllabic stress pattern, and stuttering. *Journal of Speech, Language, and Hearing Research*, *37,* 564-571.

Jensen, P. J., Markel, N. N., & Beverung, J. W. (1986). Evidence of conversational dysrhythmia in stutterers. *Journal of Fluency Disorders, 11*, 183-200.

Jescheniak, J. D., Schriefers, H., Garrett, M. F., & Friederici, A. D. (2002). Exploring the activation of semantic and phonological codes during speech planning with event-related brain potentials. *Journal of Cognitive Neuroscience, 14,* 951-964.

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,* 1862-1875.

Kiran, S. (2008). Typicality of inanimate category exemplars in aphasia treatment: Further evidence for semantic complexity. *Journal of Speech, Language, and Hearing Research, 51,* 1550-1568.

Kiran, S., & Thompson, C. K. (2003). The role of semantic complexity in treatment of naming deficits: Training semantic categories in fluent aphasia by controlling exemplar typicality. *Journal of Speech, Language, and Hearing Research, 46,* 773-787.

Klem, G. H., Luders, H. O., Jasper, H. H., & Elger, C. (1999.) The ten-twenty electrode system of the International Federation. *Electroencephalography Clinical Neurophysiology. Supplement. 52*, 3-6.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38,* 557-577.

Kutas, M. & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event related brain potential (ERP). *Annual Review of Psychology, 62,* 621-647.

Lappe, C., Trainor, L. J., Herholz, S. C., & Pantev, C. (2011). Cortical plasticity induced by short-term multimodal musical rhythm training. *PLoS ONE, 6,* 1-8.

Levelt, W. J. M. (1999). Models of word production. *Trends in Cognitive Sciences, 3,* 223-232.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

Maher, L. M., & Raymer, M. R. (2004). Management of anomia. *Journal of Top Stroke Rehabilitation, 11*, 10-21.

Mari-Beffa, P., Valdes, B., Cullen, D. J., Catena, A., & Houghton, G. (2005). ERP analyses of task effects on semantic processing of words. *Cognitive Brain Research, 23,* 293–305.

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. *Journal of Clinical Neurophysiology, 121,* 1447-1463.

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. *Journal of Clinical Neurophysiology, 123*, 1131-1146.

Meyer, D.E., Osman, A.M., Irwin, D.E., & Yantis, S. (1988). Modern mental chronometry. *Journal of Biological Psychology, 26*, 3-67.

Murray, L. L. (2012). Attention and other cognitive deficits in aphasia. *American Journal of Speech-Language Pathology, 21,* S51-S64.

Murray, F. P., & Edwards, S. G. (1980). *A stutterer's story*. Danville, IL: Interstate.

Murray, L. L., Holland, A. L., & Beeson, P. M. (1998). Spoken language of individuals with mild fluent aphasia under focused and divided-attention conditions. *Journal of Speech, Language, and Hearing Research*, *41,* 213-227.

Murray, L. L., Keeton, R. J., & Karcher, L. (2006). Treating attention in mild aphasia: Evaluation of attention process training-II. *Journal of Communication Disorders, 39,* 37-61.

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,* 196-213.

North, G. R., Bell, T. L., Cahalan, R. F., & Moeng, F. J. (1982). Sampling errors in the estimation of empirical orthogonal functions, Mon. Weather Rev., 110, 699– 706.

Nunez, P. L., & Srinivasan, R. (2006). Electrical fields of the brain: the neurophysics of EEG (Appendices J1–J3). New York: Oxford University Press.

Oomen, C. C. E., & Postma, A. (2001). Effects of divided attention on the production of filled pauses and repetitions. *Journal of Speech, Language, and Hearing Research*, *44,* 997-1004.

Otten, L. J., & Rugg, M. D. (2005). Interpreting event-related brain potentials. In T. Handy (Ed.). *Event-related potentials: A methods handbook* (pp. 3-16). Cambridge, MA: MIT Press.

Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech-in-noise. *Journal of Ear and Hearing, 30,* 653-661.

Parbery-Clark, A., Strait, D. L., Anderson, S., Hittner, E., & Kraus, N. (2011). Musical experience and the aging auditory system: Implications for cognitive abilities and hearing speech in noise. *PLoS ONE, 6,* e18082.

Pero, S., Inoccia, C., Caracciolo, B., Zoccolotti, P., & Formisano, R. (2006). Rehabilitation of attention in two patients with traumatic brain injury by means of ‘attention process training.’ *Journal of Brain Injury, 20,* 1207-1219.

Polich, J. (2010). Neuropsychology of P300. In S.J. Luck & E.S. Kappenman, *Handbook of event-related potential components*, Oxford University Press.

Postma, A., & Kolk, H. (1993). The covert repair hypothesis: Prearticulatory repair processes in normal and stuttered disfluencies. *Journal of Speech, Language, and Hearing Research, 36,* 472-487.

Postma, A., Kolk, H., & Povel, D. J. (1990). Speech planning and execution in stutterers. *Journal of Fluency Disorders, 15,* 49-59.

Preisendorfer, R. W., Zwiers, F. W., & Barnett, T. P. (1981). Foundations of principal component selection rules. Scripps Institution of Oceanography Reference Series 8:1-4.

Prins, D., & Main, V. (1997). Lexicalization in adults who stutter. *Journal of Speech, Language, and Hearing Research, 40,* 373-384.

Rabipour, S., & Raz, A. (2012). Training the brain: Fact and fad in cognitive and behavioral remediation. *Journal of Brain and Cognition, 79,* 159-179.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin*, *114*, 510-532.

Rauscher, F. H., Shaw, G. L., Levine, L. J., Wright, E. L., Dennis, W. R., & Newcomb, R. L. (1997). Music training causes long-term enhancement of preschool children's spatial-temporal reasoning. *Journal of Neurological Research, 19,* 2-8.

Rauscher, F. H., & Zupan, M. A. (2000). Classroom keyboard instruction improves kindergarten children's spatial-temporal performance: A field experiment. *Early Childhood Research Quarterly, 15,* 215-228.

Sasisekaran, J., De Nil, L., Smyth, R., Johnson, C. (2006). Phonological encoding in the silent speech of persons who stutter. *Journal of Fluency Disorders, 31*, 1-21.

Schmitt, B. M., Schiltz, K., Zaake, W., Kutas, M., & Munte, T. F. (2001). An electrophysiological analysis of the time course of conceptual and syntactic encoding during tacit picture naming. *Journal of Cognitive Neuroscience, 13,* 510-522.

Smith, A., Sadagopan, N., Walsh, B., & Weber-Fox, C. (2010). Increasing phonological complexity reveals heightened instability in inter-articulatory coordination in adults who stutter. *Journal of Fluency Disorders, 35*, 1-18.

Sohlberg, M. M., McLaughlin, K. A., Pavese, A., Heidrich, A., & Posner, M. I. (2000). Evaluation of attention process training and brain injury education in persons with acquired brain injury. *Journal of Clinical and Experimental Neuropsychology, 22,* 656-676.

Spencer, K. M., Dien, J., & Donchin, E. (1999). A componential analysis of the ERP elicited by novel events using a dense electrode array. *Psychophysiology, 36,* 409–14.

Spencer, K. M., Dien, J., & Donchin, E. (2001). Spatiotemporal analysis of the late ERP responses to deviant stimuli. *Psychophysiology, 38,* 343–58.

Strait, D. L., Parbery-Clark, A., Hittner, E., & Kraus, N. (2012). Musical training during early childhood enhances the neural encoding of speech in noise. *Journal of Brain & Language, 123,* 191-201.

Szekely, A., Jacobsen, T., D'Amico, S., Devescovi, A., Andonova, E., Herron, D., Lu, C.C., Pechmann, T., Pléh, C., Wicha, N., Federmeier, K., Gerdjikova, I., Gutierrez, G., Hung, D., Hsu, J., Iyer, G., Kohnert, K., Mehotcheva, T., Orozco-Figueroa, A., Tzeng, A., Tzeng, O., Arévalo, A.L., Vargha, A., Butler, A.C., Buffington R., & Bates, E. (2004). A new on-line resource for psycholinguistic studies, *Journal of Memory and Language, 51,* 247–250.

Tan, L. H. & Perfetti, C. A. (1999). Phonological and associative inhibition in the early stages of English word identification: evidence from backward masking. *Journal of Experimental Psychology: Human Perception & Performance, 25,* 382–93.

Van Lieshout, P. H. H. M., Hulstijn, W., & Peters, H. F. M. (1996). Speech production in people who stutter: Testing the motor plan assembly hypothesis. *Journal of Speech, Language and Hearing Research*, *39*, 76-92.

Van Petten, C. (1995). Words and sentences: Event-related brain potential measures. *Psychophysiology, 32,* 511–25.

Van Petten, C., & Kutas, M. (1991). Electrophysiological evidence for the flexibility of lexical processing. In G. Simpson (Ed.). *Understanding word and sentence* (pp. 129-174). Amsterdam: Elsevier.

Van Turennout, M., Hagoort, P., & Brown, C. (1999). The time course of grammatical and phonological processing during speaking: Evidence from event-related brain potentials. *Journal of Psycholinguistic Research, 28,* 649-676.

Van Turennout, M., Hagoort, P., & Brown, C. (1997) Electrophysiological evidence on the time course of semantic and phonological processes in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 787-806.

Vincent, I., Grela, B. G., & Gilbert, H. R. (2012). Phonological priming in adults who stutter. *Journal of Fluency Disorders, 37*, 91-105.

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory- Is younger better? *Journal of Developmental Review, 32,* 360-387.

Watkins, R. V., & Yairi, E. (1997). Language production abilities of children whose stuttering persisted or recovered. *Journal of Speech, Language, and Hearing Research, 40,* 385-399.

Watson, B. C., Freeman, F. J., Devous, M. D., Chapman, S. B., Finitzo, T., & Pool, K. D. (1994). Linguistic performance and regional cerebral blood flow in persons who stutter. *Journal of Speech, Language, and Hearing Research, 37,* 1221-1228.

Weber-Fox, C. (2001). Neural systems for sentence processing in stuttering. *Journal of Speech, Language, and Hearing Research, 44,* 814-825.

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,* 1058-1071.

Wijnen, F., & Boers, I. (1994). Phonological priming effects in stutterers. *Journal of Fluency Disorders, 19,* 1-20.

Yaruss, J. S. (2010). Assessing quality of life in stuttering treatment outcomes research. *Journal of Fluency Disorders, 35,* 190-202.

Yaruss, J. S., & Bernstein Ratner, N. (2010). Becoming an effective clinician for people who stutter: You can do it! *Seminars in Speech and Language, 31,* 283-286.

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,* 90-115.