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Attentional Allocation in Language Processing in Adults Who Stutter: ERP Evidence

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Attentional Allocation in Language Processing in Adults Who Stutter: ERP Evidence

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Speech Language Pathology
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ABSTRACT

The aim of this study was to investigate how young adults who stutter allocate attentional resources during two linguistic stages in picture naming, specifically lemma and lexeme retrieval. This study reports on behavioral and brain electrophysiological data collected during a simple auditory oddball task and a Dual Picture-Word Interference/Tone Monitoring Task.
CHAPTER ONE: INTRODUCTION

Background

Developmental stuttering persists into adulthood in slightly <1% of the population and generally affects males (at a 3:1 ratio) more than females (Bloodstein, 1995; Craig, Hancock, Tran, Craig, & Peters, 2002; Yairi & Ambrose, 2013; 2015). Stuttering has been defined as interruptions in fluent speech patterns that involve a lack of movement within the speech mechanism (Wingate, 1964). In adults, this lack of movement can present as part-word and syllabic repetitions, audible prolongations, and silent blocks (Wingate, 1964). These interruptions are commonly accompanied by concomitant behaviors which may make speech production appear as a struggle (Vanryckeghem, Brutten, Uddin, & Van Borsel, 2004).

Individuals report a range of emotional states regarding their stuttering, such as excitement, anxiety, embarrassment, and fear (Wingate, 1964; Guitar, 2006; Maxfield, Huffman, Frisch, & Hinckley, 2010).

Crucially, the social and emotional impact of stuttering can negatively affect an adult’s quality of life. For example, as reported by Iverach and colleagues (2009) persistent stuttering can contribute to negative perceptions of communicative ability. It may also lead to maladaptive behavior, such as social avoidance or unhealthy cognitive reactions (e.g., increased negative thought patterns). Stuttering can impact vocational opportunities too. For example, Klein and Hood (2004) reported that at least some adults who stutter (AWS) report that they feel stuttering interferes with their ability to procure a job. Additionally, AWS felt that stuttering was a
handicap and hindered their ability to perform their job duties efficiently, specifically when communication was required (see also Yaruss, 2001). It was also reported that as many as 20% of AWS have turned down a job position due to their stuttering. Still other evidence suggests that people with communication disorders, including stuttering, are financially less viable (Ruben, 2000). As a whole, the findings outlined here indicate that stuttering in adulthood can have significant negative impacts on social-emotional and vocational well-being (Corcoran & Stewart, 1998; Menzies, Onslow, & Packman, 1999; Ginsberg, 2000; Yaruss, 2001; Messenger, Onslow, Packman, & Menzies, 2004; Beilby 2013; Beilby, Byrnes, Meagher, & Yaruss, 2013).

Even more severe than quality of life impacts, stuttering may also affect mental health (Yaruss, 2010; Beilby et al., 2013). Recently, it was reported that 72% of adults who stutter met the criteria for diagnosis of at least one mental health disorder (Iverach, O’Brian, Jones, Block, Lincoln, Harrison, & Onslow, 2009). Noteworthy is that stuttering severity in adults positively correlates with feelings of anxiety and depression (Craig, 2003; Craig, Blumgart, & Tran, 2009). Although there is not a disproportionately high rate of mental health disorders in people who stutter as a group, adults with particularly severe stuttering and who were often teased as children have been shown to exhibit higher-than-usual rates of generalized anxiety disorder (Craig et al., 2009).

Mechanistically, producing speech involves both language processing and motor speech processing. The speaker begins with an idea, or concept, he or she wishes to communicate. The end result is an articulated phonological representation that conveys the intended message. During this time, the speaker rapidly processes linguistic and motor information in preparation to produce the target message. In picture naming – a useful analogue of this process (Glaser, 1992) - visual feature processing of a pictured object activates concepts (Bierwisch & Schreuder, 1992;
Collins & Loftus, 1975; Roelofs, 1992, 1997) which, in turn, activate associated lexical items (hereafter, lexical-semantic processing). Lexical items then compete until one emerges having the greatest activation and is selected (Levelt, Roelofs, & Meyer, 1999). The phonological code for that lexical item is then retrieved (hereafter, phonological processing) (Berg & Schade, 1992; Bock & Griffin, 2000). The target utterance is then prepared for articulation through processes in speech motor planning and programming (Munhall, Kawato, & Vatikiotis-Bateson, 2000).

There is vast evidence that stuttering is associated with deficits in speech motor ability (Conture, Walden, Arnold, Graham, Hartfield, & Karrass, 2006; Max & Gracco, 2005; Loucks & De Nil, 2006; Smith, Sadagopan, Walsh, & Weber-Fox, 2010; Namasivayam & van Lieshout, 2011). For example, Smith and colleagues (2010) reported that increasing the phonological length and complexity of utterances can destabilize the inter-articulatory system of AWS. Additionally, van Lieshout and colleagues (2014) reported that during an Emotion and Classical Stroop task, AWS responded more slowly to stimulus items (naming target words) and smaller upper lip movement than typically fluent adults (TFA), demonstrating differential motor responses. A third study (Caruso, Abbs, & Gracco, 1988) found that AWS demonstrated longer duration movements during articulatory and phonation tasks than TFA. Similarly, Max and Gracco (2005), found AWS had longer duration times during the production of target phonemes than TFA in the oral and laryngeal subsystems.

Not surprisingly, interventions for adulthood stuttering focus primarily on motor speech relearning. Fluency shaping (FS) and stuttering modification (SM) are the two principle behavioral approaches to the treatment of adulthood stuttering (Blomgren, Richburg, Rhodehouse, & Redmond, 2012). FS aims to establish stutter free speech, while SM aims to establish stuttering without unnecessary tension or struggle (Prins & Ingham, 2009). The two
approaches may be combined to form a comprehensive treatment for stuttering (Blomgren, 2010). Whether used in isolation or alongside SM, FS involves teaching prolonged speech type techniques (e.g., prolonged/continuous phonation, slow articulatory movements, easy voicing and light articulatory touches) that allow the production of speech without fluency disruptions (Prins & Ingham, 2009). As reviewed in Bothe et al. (2006), AWS can benefit from therapy that teaches prolonged speech type techniques, particularly in an intensive setting, with a group format, featuring targeted transfer activities, with heavy emphasis on self-evaluation, and a performance contingent maintenance program. Additional evidence for these conclusions has been reported in recent years (Fry, Botterill, & Pring, 2009; Irani, Gabel, Daniels, & Hughes, 2012; Teshima et al., 2010).

On the other hand, adults who stutter often relapse after intervention (McClure & Yaruss, 2003). Namasivayam and van Lieshout (2011) conducted a meta-review on speech motor skills and AWS. Their findings conclude that AWS differ from TFA in their ability to practice, change and maintain newly acquired motor speech skills in the long run. Several factors may contribute to relapse, including 1) demanding contexts (i.e., work environments, interviews, and telephone communication), 2) speaking in front of authoritative figures (i.e. a boss, co-workers, public presentations, etc.), 3) lack of maintenance strategies following treatment, 4) inability to adjust to the role of a fluent speaker and 5) negative emotions (Craig & Hancock, 1995; DiLollo, Neimeyer, & Manning, 2002).

Another potential contributing factor is that interventions incompletely address the deficit. The focus here is on attentional demands in language production in AWS. As reviewed below, there is mixed evidence about how real-time language processing operates in AWS. One fairly recent and still tentative finding is that AWS may allocate disproportionate attentional
resources to lexical access (Maxfield et al., 2010, 2012, 2014). One aim of this study was to explicitly investigate this hypothesis. There is also mixed evidence that AWS possess limited attentional resources available to support speech production functions. Therefore, a second aim was introduced to investigate attentional capacity in AWS in the absence of any language or motor speech demands. Both questions were investigated using mixed behavioral and brain electrophysiological measures. Results may inform the inclusion of a focus on language and attentional control in interventions for adulthood stuttering.

**The Role of Attention in Language Production**

In order to produce fluent speech, the speaker must process linguistic knowledge efficiently. Furthermore, word production is complex and involves several underlying processes. These processes are quick and, normally, accurate. In fact, speakers can engage in a naming task and produce a target word within 600 msec following stimulus onset (Levelt, Roelofs, & Meyer; 1999). For single word production, this process entails the translation from concept to word to sounds. In picture naming - a useful analogue of speech production (Glaser, 1992) - a visually-activated concept is associated with a word (lexical-semantic processing), that word's phonological code is retrieved (phonological processing) and produced as coordinated gestures (articulation).

More than a decade ago, Ferreira and Pashler (2002) investigated whether language production is supported by domain-specific cognitive resources (i.e., those "dedicated" to language processing) versus domain-general cognitive resources (i.e., central cognitive resources supporting a broad range of human functions). Their research demonstrated that lexical-semantic processing draws on domain-general resources. Later research (Cook & Meyer, 2008; Roelofs, 2008) demonstrated that phonological processing in language production also consumes domain-
general cognitive resources. These and other findings have been used to support the claim that language production demands at least some form of attention, or central cognitive control.

The specific role of attention in lexical access is to regulate the allocation of central cognitive resources to lexical-semantic and phonological processing (Roelofs & Piai, 2011). For example, attention enhances the activation of target concepts and words (lexical-semantic processing) until the phonological and articulatory properties of those words can be encoded. Roelofs (2011) suggested that this role of attention is particularly important, because concepts and phonological forms are only distantly-connected in the network structure of the mental lexicon. Thus, conceptual and lexical information associated with a target picture name needs to be sustained until sufficient activation can spread through the mental lexicon to the phonological code for that picture name. The precise amount of cognitive resources necessary to support language production can vary from context to context, and may have implications for other processes in speech production (e.g., motor readiness) because humans possess a finite amount of attention (Kahneman, 1973). For example, there is evidence that when speech production becomes particularly attentionally-demanding motor speech performance can break down even in TFA (Dromey & Benson, 2003).

Similarly, a ‘demands-and-capacities’-type model has also been proposed in relation to stuttering. According this model, adequate capacity in motor planning, linguistic ability, emotional regulation, and cognitive ability is necessary to produce speech fluently (Starkweather & Givens-Ackerman, 1997; Starkweather, 2002). Within this model, these four domains are not mutually exclusive and can act together to impede fluency. The so-called ‘Demands-and-Capacities’ (DCM) model of stuttering stipulates that there is a finite amount of attention an individual possesses. As demands on speaking increase, any of the four domains mentioned
previously (motor planning, language, emotion, cognition) may consume increasing resources, leaving limited central resources available to support the other processes and, ultimately, diminishing fluency. As outlined in the following sections, there is limited evidence to suggest that language production may be particularly attentionally-demanding in AWS.

**Lexical-Semantic Processing in AWS**

Limited evidence exists of real-time language production in AWS. Max and colleagues (2004) reported that disruptions of speech production in AWS can possibly be explained by, in part, unstable or incomplete activation of semantic or phonological encoding. It is thought that AWS experience breakdowns in speech production due to poor lexical selection (Postma & Kolk, 1993). It has been reported that on test of word associations, AWS responded just as fast (Crowe & Kroll, 1991; Taylor, Lore, & Waldman, 1970) or faster (Jensen, Markel, & Beverung, 1986) than TFA. This suggests that AWS and TFA can effectively activate words related to specific categories or themes. Although, AWS were also shown to produce words that had greater variance from the intended conceptually appropriate word-forms and required longer naming times (Crowe & Kroll, 1991), suggesting that there may be inconsistencies of semantic activation-spreading in AWS when compared to TFA.

Additional research has investigated naming tasks that required more specific responses from AWS. For example, during a picture naming task, it was reported that AWS produced more naming errors than TFA (Newman & Ratner, 2007), indicating that target words engage in a competition with similar or unrelated word forms. When a naming error occurs, it is thought that the resolution of the competition resulted in the activation of an inaccurate word form, opposed to the target response. Notably, it is thought that target word forms do not activate unusually high competition with distant semantic neighbors (Hennessey, Nang, & Beilby, 2008). Another study,
using a task that required providing definitions for a specific word, reported AWS produced more verbose definitions but used fewer synonyms than TFA (Wingate, 1988). Additionally, AWS scored lower than TFA on a norm-referenced test of word finding (Pellowski, 2011). These results suggest AWS demonstrate reduced activation of conceptually appropriate words.

Furthermore, Bosshardt (2006) reported AWS stuttered less in sentences that weren’t as robust in semantic content, when paired with an unrelated secondary task. Implicating that, perhaps, AWS maintain verbal fluency by allocating limited attentional resources (i.e., those not consumed by the secondary task) away from lexical-semantic processing, instead directing those resources toward processes in phonological encoding and motor speech production. Conversely, TFA tend to preserve semantic content but adopt a simpler strategy in order to maintain verbal fluency when producing sentences under dual-task demands (Kemper, Herman, & Nartowicz, 2005). One possibility is that lexical-semantic processing is particularly attentionally-demanding in AWS and, thus, sacrificed to preserve fluency when attention resources are limited. Alternatively, phonological and/or motor speech production may be particularly attentionally-demanding in AWS, forcing lexical-semantic processing to be sacrificed.

**Phonological Processing in AWS**

Phonological processing entails the string of sounds that form a word and are activated for articulation (Dell, 1986; Levelt, Roelofs, & Meyer, 1999). Results in the literature regarding phonological processing in AWS suggest possible deficits in phonological encoding. One example of this is that the rate of stuttering is sensitive to frequency effects on word form retrieval. Retrieval of lower-frequent word-classes elicit more speech errors than high-frequent word classes in TFA (Stemberger & MacWhinney, 1986; Dell, 1990) and can increase moments of stuttering in AWS (Newman & Ratner, 2007).
Hennessey and colleagues (2008) utilized a phonological priming manipulation in a word production experiment and found no atypical phonological encoding in AWS. However, Postma and colleagues (1990) have found evidence of phonological processing decrements in AWS using sub-vocalized phonological tasks (Sasisekaran et al., 2006; Sasisekaran & De Nil, 2006; Bosshardt & Nandyal, 1988; Postma et al., 1990; Hand & Haynes, 1983; Rastatter & Dell, 1987). These findings hint at implicit differences in phonological encoding that do not always impact overt speech production. From an attentional perspective, these results suggest that AWS may demonstrate differences in phonological encoding that are not cognitively taxing enough to draw attentional resources away from processes in motor speech production.

Alternatively, studies investigating the impact of cognitive processing demand in phonological code activation found that increased cognitive load in phonological encoding both slowed sub-vocalized phonological judgments in AWS (Weber-Fox, Spencer, Spruill, & Smith, 2004; Jones, Fox & Jacewicz, 2012) and affected overt speech production in AWS (Postma & Kolk, 1990; Eldridge & Felsenfed, 1998; Brocklehurst & Corley, 2011; Byrd, Vallely, Anderson & Sussman, 2012). These results suggest that phonological encoding requirements can be attentionally-demanding enough in AWS as to limit the availability of attentional resources to support other functions (e.g., processes in motor speech production).

**Limitations and Extensions of Language Production Research with AWS**

One factor limiting the sustainability of evidence outlined in the preceding sections was a heavy reliance on behavioral methods to index real-time processing in language production in AWS. For example, reaction time (RT) measures, used prominently to date in language production research with AWS, can differ in AWS versus TFA even in the absence of task demands on word retrieval (Bloodstein and Ratner, 2008). Furthermore, as described in Meyer et
al. (1988), “Because standard behavioral measures obtained through mental chronometry represent the total duration and final output of many processing stages in combination, they do not offer an especially close look at underlying component processes” (p. 41).

One advancement has been to use brain event-related potentials (ERPs) to investigate real-time language processing with increasing precision. Scalp-recorded ERPs reflect at least some of the electrophysiological activity generated by the brain as people process stimuli, make decisions and regulate behavior. As described in Hagoort and Kutas (1995), "...in contrast to RTs which are punctate, ERPs are co-extensive with the linguistic stimulation and beyond. It is thereby possible to monitor the immediate consequences of a particular experimental manipulation (e.g., a syntactic or semantic violation) as well as its downstream effects, if any" (p.109). Crucially, averaged ERP activity can be decomposed into several different components, many of which reliably index very specific language or cognitive processes (Otten & Rugg, 2005).

Since the late 1990s, ERPs have been used to investigate hypotheses about mechanisms of language production in TFA. In some of the earliest work of this type, two ERP components (lateralized readiness potential and No-Go N200) were used to study the relative timing of semantic, grammatical and phonological encoding processes in TFA (van Turennout et al., 1997, 1998; Schmitt et al., 2000, 2001a,b; Abdel Rahman et al., 2003; Schiller et al., 2003), as well as the interaction of these different processing levels (Schiller et al., 2003). At around the same time, N400-like components were utilized to study the direction and extent of activation spreading through the mental lexicon during language production in TFA (Jescheniak et al., 2002, 2003). Error-related ERP components have also been employed to investigate mechanisms of self-monitoring during language production in TFA (Ganushchak and Schiller, 2006, 2008a,b,
More recent work, reviewed in Ganushchack et al. (2011), has continued using paradigms combining ERPs and language production to investigate the time-course of lexical retrieval stages from lemma to lexeme (e.g., Eulitz et al., 2000; Koester and Schiller, 2008; Costa et al., 2009; Dell’Acqua et al., 2010), the locus of picture-word interference effects in lexical retrieval (Dell’Acqua et al., 2007; Hirschfield et al., 2008; Aristei et al., 2011), and language production in bilingualism (Christoffels et al., 2007; Chaunsey et al., 2009; Verhoef et al., 2009). This same approach has also been extended to investigate language production after stroke (Laganaro et al., 2009; 2011) and, as discussed in previous sections, in stuttering.

Brain electrophysiological measures are not new in research on stuttering. For example, a number of studies, some of them dating back decades, have compared known ERP components in AWS versus TFA. Among others, these studies have examined contingent negative variation (e.g., Zimmerman and Knott, 1974; Pinsky and McAdam, 1980; Prescott and Andrews, 1984; Prescott, 1988), P300 activity (e.g., Ferrand, Gilbert and Blood, 1991; Morgan et al., 1997; Hampton and Weber-Fox, 2008; Sassi et al., 2011), error-related components (Arnstein et al., 2011) and auditory evoked potentials (Hampton and Weber-Fox, 2008; Liotti et al., 2010; Maxfield et al., 2010).

Of particular relevance is the work of Christine Weber-Fox and colleagues, who have used ERPs to investigate language processing in AWS in receptive mode (i.e., during word recognition and sentence processing). For example, Weber-Fox (2001) reported that AWS versus TFA evidenced attenuated ERP effects to both grammatical and semantic word classes during a sentence reading task. In a later study, Weber-Fox et al. (2004) reported that ERP correlates of phonological processing, elicited during a rhyme judgment task for pairs of printed words, were
similar in AWS and TFA. The former findings were taken to indicate that neural functions related to lexical retrieval may be altered in AWS, while the latter findings were taken to indicate that adulthood stuttering may not stem from phonological processing deficits. This line of work has also been extended to investigate syntactic processing in AWS (e.g., Cuadrado and Weber-Fox, 2003; Weber-Fox and Hampton, 2008). As discussed in Maxfield et al. (2012), it remains an open question whether differences observed between AWS and TFA in receptive language processing generalize to language production (although see Pickering and Garrod, 2007, 2013).

**ERP Studies of Real-Time Language Production in AWS**

In three recently-published experiments (Maxfield et al., 2010; 2012; 2014), Maxfield and colleagues began using ERPs to investigate lexical-semantic and phonological processing in AWS on the path to picture naming. In Maxfield et al. (2010), aims investigated whether lexical-semantic processing in picture naming operates similarly in AWS versus TFA, using ERPs recorded during a picture-word priming task adopted from Jescheniak et al. (2002). On most trials of that experiment, a picture was presented followed 150 milliseconds (ms) later by an auditory probe word. 1500 ms after the probe word, a cue to name the picture appeared on the screen (i.e., pictures were named at a delay so as to limit muscle artifact during processing of the auditory probe words, to which ERPs were recorded). Probe words were semantically associated with the target picture labels, or semantically- and phonologically-unrelated. Instructions were to prepare to name the picture on each trial, ignore the auditory probe word (so as to deemphasize phonological processing of the probes), and name the pictures when cued. The basic expectation was that the N400 ERP component, which indexes contextual priming in language processing (Kutas & Federmeier, 2011), should be elicited to the auditory probe words and attenuated in amplitude when the labels of pictures preceding the probes were semantically-related versus
unrelated. This standard semantic N400 priming effect was seen in TFA. However, a reverse semantic N400 priming effect (larger amplitudes for semantically-related versus unrelated probes) was seen for AWS. One interpretation proposed for the atypical reverse N400 priming effects produced by AWS, was that - at picture onset - semantic associates of the target picture labels were atypically inhibited. When those neighbors subsequently appeared as probe words, enhanced processing was necessary to reactivate (or disinhibit) them, indexed by an enhanced N400 amplitude on semantically-related trials. We likened this effect to ‘center-surround inhibition’, a compensatory attentional mechanism for retrieving words poorly-represented in the mental lexicon (Dagenbach et al., 1990). 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). Reverse N400 priming effects have also been observed in TFA in antecedent conditions simulating center-surround inhibitory processing (Mari-Beffa et al., 2005; Bermeitinger et al., 2008; Deacon et al., 2013).

In Maxfield et al. (2012), it was investigated whether phonological processing in picture naming operates similarly in AWS versus TFA, also using ERPs recorded in a picture-word priming task. On most trials of that experiment, a picture was presented followed 150 ms later by an auditory probe word, and then a cue to name the picture 1500 ms later. Once again, ERPs were recorded to the probe words, which were either phonologically-related to the target picture labels, or semantically- and phonologically-unrelated. Task instructions were modified from Maxfield et al. (2010) such that, instead of ignoring the auditory probe words, participants here were required to remember them (so as to emphasize phonological processing of the probes).
After the picture was named on each trial, participants were asked to verify the auditory probe word. Once again, the expectation was that the N400 ERP component should be elicited to the auditory probe words and attenuated in amplitude when the labels of the pictures preceding the probes were phonologically-related versus unrelated. This phonological N400 priming effect was seen for TFA. However, a reverse phonological N400 priming effect (larger amplitudes for phonologically-related versus unrelated probes) was seen in AWS. Again, we speculated that - at picture onset - phonological associates of the target picture labels were atypically inhibited. When those neighbors subsequently appeared as probe words, enhancements in processing were necessary to reactivate (or disinhibit) them, indexed by enhanced N400 amplitude on phonologically-related trials. The main implication of these two studies was that AWS may engage in atypical inhibitory processing during language production.

In Maxfield et al. (2014), we investigated whether a paradigm other than picture-word priming would also reveal atypical processing in language production in AWS. Our concern was that picture-word priming is still a fairly off-line approach, i.e., probe word-elicited N400 activity is used to draw inferences about upstream processing of self-generated picture labels. Additionally, picture-word priming imposes fairly artificial task demands (e.g., each picture is named at a delay, after the auditory probe has been presented, followed in some designs by probe word verification). Thus, it is possible that atypical results seen for AWS in (Maxfield et al., 2010, 2012) were, at least in part, task artifacts. In Maxfield et al. (2014), the aim was to investigate language processing during, rather than immediately after, picture naming in AWS - and without the artificial task demands imposed by picture-word priming. For this purpose, we adopted a modified version of a masked picture priming paradigm from Chauncey et al. (2009). On each trial, a picture was presented, which was to be named immediately, emphasizing
accuracy over speed. The picture was preceded by a masked printed prime word, which was barely perceptible to participants if at all. Prime words were either identical to the target picture labels, or semantically- and phonologically-unrelated. ERPs were recorded from picture onset. The basic question was whether identity priming modulated picture-evoked ERP activity similarly in AWS versus TFA. Among other findings, a P280 ERP component was modulated with priming in AWS but not TFA. P280 has been associated with enhanced focal attention to facilitate processing of target words under attentionally-demanding conditions (Rudell & Jian, 1996; Mangels et al., 2001).

We proposed three different scenarios for why AWS might need to enhance focal attention on the path to picture naming (supporting details are in Maxfield et al., 2014). First, it is possible that target words activate unstably on the path to naming due to impoverished or atypical connections in the mental lexicons of AWS. A second possibility is that, instead of target words activating unstably in AWS, their semantic or phonological neighbors become too strongly activated. A third possibility is that there are insufficient attentional resources to support word production in AWS, resulting in unstable activation of target words on the path to naming. In any of these scenarios, there may be less differential activation of the target word in comparison to its competitors. A reasonable compensatory strategy would be for AWS to enhance focal attention to ensure stable activation of target words (i.e., center-surround inhibition). Controlled lexical processing of this sort is also suspected in people with Broca’s aphasia (see Bushell, 1996 and Blumstein et al., 2000).

**Current Study**

The possibility that a ‘center surround inhibition’ mechanism may mediate processes in language production in AWS raises an important question, namely whether language production
draws disproportionate resources away from secondary task processing. This can be addressed by pairing a) picture naming tasks that heighten competition in lexical retrieval with b) a secondary non-linguistic task that demands attention concurrently with picture naming. An example is the task used by Ferreira and Pashler (2002) to investigate central resource consumption in word retrieval. Participants engaged in a PWI task (Task 1) while judging the pitch of tones (Task 2). Tones presented in close proximity to pictures elicited longer RTs than tones presented distally, consistent with a psychological refractory period effect. In semantic PWI, naming RTs were prolonged (the standard semantic PWI effect) and, crucially, tone judgment RTs increased relative to a control condition. This indicates that lexical-semantic processing interferes with tone discrimination (as tone judgment times would otherwise have been unaffected). In phonological PWI, naming RTs were shortened but tone judgment RTs were unaffected. Roelofs (2008), however, found that phonological PWI affected Task 2 judgment RTs for visual rather than auditory discrimination.

In the current experiment, we modified the Ferreira and Pashler (2002) task to include ERP in addition to RT measures. The ERP component of interest here is P3b, which can be used to index attentional capacity and control (Nieuwenhuis, Aston-Jones, & Cohen, 2005). Picton (1992) described the P3 wave as representing “the transfer of information to consciousness, a process that involves many different regions of the brain” (p. 456). Another theory is that the P300 indexes a series of cognitive processes related to the updating of working memory, context closure, and event-categorization (Donchin & Cole, 1988).

A standard experimental approach for eliciting P3b involves presenting frequent stimuli interspersed with infrequent stimuli, the standard oddball paradigm (Dien, Spencer, & Donchin, 2004). Typically, attention to the stimuli is required, and there are task-defined stimulus
categories (e.g., participants are required to press a button to infrequent, or Target, tones). Relative to frequent stimuli, ERP activity elicited by infrequent stimuli typically has larger positive-going amplitude, most prominently at posterior electrode sites (Spencer, Dien & Donchin, 2001). This is the so called P3b component. Luck (1998) defines P3b amplitude as a relatively pure measure of attentional resources available for perception and categorization of stimuli. As described by Luck, the amplitude of the P3b component can be attenuated when “perceptual processing resources” are diverted from the eliciting stimuli in a dual task paradigm. In contrast, P3b latency as the time needed to perceive and categorize target stimuli. The current study was focused on P3b amplitude.

To date, there have been a handful of studies investigating P3 as a measure of cognitive processing in AWS. Ferrand, Gilbert, and Blood (1991) compared P3 amplitude, laryngeal shift, and vocal fold vibration onset between TFA and AWS. They observed no significant P3 amplitude differences between AWS and TFA. Khedr and colleagues (2000) reported similar results. In their auditory oddball task, AWS did not demonstrate any P3 amplitude or latency differences when compared with TFA. Kheder et al. (2000) also compared P3 between groups in a visual oddball task and found no significant differences in that task, too. In contrast, other studies report evidence of differing P3 morphology between AWS and TFA (Morgan, Cranford, & Burk, 1997; Hampton & Weber-Fox, 2008; Sassi, Matas, Medonca, & Andrade, 2011; Idiazabal, Vila, Sangorrin, & Espdaler, 2000). Morgan, Cranford, and Burk (1997) observed significant differences in hemispheric activity between AWS and TFA. However there were no significant differences detected between TFA and AWS in P3b amplitude or latency. Hampton and Weber-Fox (2008) investigated P3 amplitude and latency using an auditory oddball task with a short and long inter-stimulus interval. Behaviorally, TFA trended toward better accuracy and
faster response times than AWS. Additionally, in the short inter-stimulus interval condition, TFA tended to have larger P3 amplitudes and reduced latencies when compared with AWS. Idiazabal and colleagues (2000) reported significantly longer auditory P3 latencies in AWS versus TFA. However, differences in P3 amplitude were not detected. Still, other research has focused on P3 amplitudes pre-versus-post intervention. In two studies, AWS showed similar P3b morphology versus TFA pre-intervention, and P3 morphology was not shown to change post-intervention with AWS (Blomgren et al., 2012; Sassi et al., 2011). On the other hand, Sassi and colleagues (2011) did observe changes in P3 morphology post-intervention, and also found reductions in stuttering correlated positively with changes in P3 amplitude. Overall, these results paint a mixed picture regarding P3-indexed attentional capacity and control in AWS. At least some of the results outlined here suggest that P3-indexed attentional control may vary in AWS versus TFA, even in the absence of linguistic demands.

**Summary and Research Questions**

In order to investigate attentional demands of language production stages in AWS, we recorded tone-elicited ERPs in a modified version of the dual PWI/tone discrimination task used in Ferreira and Pashler (2002). Tones were low or high in pitch, occurred relatively frequently (low tones) or infrequently (high tones, requiring a button press), close in proximity to picture onset (Short Tone SOA = 50 ms) or far in proximity from picture onset (Long Tone SOA = 900 ms), following pictures overlaid with Unrelated, Semantically-related or Phonologically-related Distractors. Analysis aimed to determine whether P3b amplitude was influenced by Tone Stimulus Onset Asynchrony (SOA), Distractor Type and/or the interaction of these factors similarly between groups. If lexical-semantic and/or phonological processes in language
production are particularly attentionally-demanding in AWS, then we would expect disproportionately attenuated P3 amplitudes at the Short Tone SOA in either condition.

We also compared P3 amplitude in AWS versus TFA in a simple oddball tone monitoring experiment. This was included based on previous evidence that behavioral correlates of attentional control (e.g., Heitmann, Asbjørnsen & Helland, 2004) as well as P3 morphology can differ in AWS versus TFA, even in the absence of language production demands (e.g., Morgan, Cranford, & Burk, 1997; Hampton & Weber-Fox, 2008; Sassi et al, 2011). The interest in the current study was specifically P3 amplitude. Reduced P3 amplitudes for AWS versus TFA in a simple oddball task would point to reduced attentional capacity or control for AWS even in the absence of language production demands.
CHAPTER TWO: METHOD

Participants

Participants were 15 TFA (5 male, mean age = 23 years, 8 months) and 15 AWS (12 male, mean age = 26 years). The difference in age between groups was not statistically significant (t(28) = 1.35, p = .19). Crucially, P3b amplitude is shown to be attenuated in women versus men (Conroy & Polich, 2007), raising some concern about the different numbers of women versus men in each of our two groups (i.e., P3 amplitude might be expected to be attenuated in the TFA versus AWS due to a greater proportion of female participants). However, as reported in the Results, this was not shown to be the case. All participants were right-handed.

Each participant gave written informed consent before testing, and received $50 upon completion. At time of testing, participants reported that they were in good health, had no history of neurological injury or disease, were not taking medications that affect cognitive functions, had normal or corrected-to-normal vision, had normal hearing, and had typical speech and language abilities. All were born in the United States, spoke English as their only language, and minimally had a high-school education. Specifically, 7 TFA had a high school education or GED equivalent, 1 completed vocational technical school, 6 had an earned undergraduate college degree, and 1 had an earned master’s degree. Five AWS had a high school education or GED equivalent, 1 completed vocational technical school, 6 had an earned undergraduate college degree, 2 had an earned master’s degree, and 1 had an earned doctoral degree.
The Peabody Picture Vocabulary Test, Fourth Edition, Form B (PPVT-4; Dunn & Dunn 2007) and the Expressive Vocabulary Test, Second Edition, Form B (EVT-2, Williams, 2007) were administered to assess receptive and expressive vocabulary knowledge, respectively. Group did not affect PPVT-4 scores (TFA mean score = 107.76, SD = 9.54; AWS mean score = 104.59, SD = 10.33) (t(28) = .81, p = .43). Minimally, all participants scored within one standard deviation from the mean on the PPVT-4, with two AWS and three TFA scoring better than two standard deviations above the mean (two AWS also scored one point below two standard deviations above the mean). Nor did Group affect EVT-2 scores (TFA mean score = 104.94, SD = 10.04; AWS mean score = 100.29, SD = 10.17; t(28) = 1.12, p = .27). Minimally, all participants scored within one standard deviation from the mean on the EVT-2. Three TFA and two AWS scored better than two standard deviations above the mean on the EVT-2. In general, the groups were well-matched by age, educational level, and receptive/expressive vocabulary knowledge. Note that hearing was not assessed.

Stimuli

Stimuli for the dual-task experiment included 25 target and 25 filler black-line drawings of common objects. Each drawing elicited a single noun label, in English, with 90% or better agreement, according to norms from the International Picture Naming Project (IPNP); (Szekely et al., 2004). The 25 targets comprised a subset of stimuli used by Damian and Martin (1999) in their series of picture-word experiments (18 drawings match those in D&M-Appendix A, and 7 drawings match those in D&M-Appendix B).

Each of the 50 drawings was assigned three distractor words. One was categorically-related to the label, the second was phonologically-related (minimally sharing the initial two phonemes and the initial two letters), and the third was unrelated in form or meaning. With two
exceptions, the distractors assigned to the 25 target drawings were the same used by Damian and Martin (1999). Two target distractors were replaced to prevent duplication, as they were assigned to more than one picture in the D&M stimulus sets. Three distractor words were also assigned to each of the 25 filler pictures, with an eye toward matching the average frequency of filler distractors with those of target distractors.

**Procedure**

Testing had three components. First, each participant completed a simple oddball tone monitoring task in which low (1000Hz) and high (1500Hz) pure tones, each 60 ms in duration, were presented continuously at an SOA of 2000 ms at 70 dB HL. The probability of Standard (low) versus Target (high) tones was 75% versus 25%. Participants were instructed to press a button to high tones, using the index finger of their right hand, as quickly and accurately as possible. 180 trials comprised this task, ~6 minutes in duration. Continuous EEG was recorded during this task as described in the Recording and Apparatus section.

Next, participants were familiarized with the 50 black-line drawings selected for the main task, after which they completed a practice task. Participants were told that, in addition to discriminating Target (High) versus Standard (Low) tones, a picture-distractor word pair would appear on each trial. Instructions were to name the picture, as quickly and accurately as possible, while judging the tone. Practice included 100 trials (each of the 25 filler pictures, presented twice with its unrelated distractor word, with each tone type at each tone SOA). Trial structure was the same as in the main task. EEG was not recorded during this warm-up task.

For the main task, 600 trials were presented in a single, large block. Each trial included a crosshair (+) presented for 500 ms, replaced by a Picture-Distractor pair, followed by a (1000Hz
or 1500Hz) tone at an SOA of either 50 ms or 900 ms relative to picture onset. Distractor word SOA was always 0 ms relative to picture onset. The distractor word on each trial was masked (using 7 upper-case Xs) at 200 ms after picture onset. Trials were separated by a 500-ms intertrial interval, during which a blank screen was shown. The time-out period for responding was 3000 ms for naming and 2500 ms for tone judgments. Each picture appeared a total of 12 times. Each target picture appeared with each of its three distractor words, once with the Standard (Low) tone at each tone SOA, and once with the Target (High) tone at each tone SOA. To achieve an oddball effect (75% low tones, 25% high tones), each filler picture appeared with each of its three distractor words, only with a Standard (Low) tone, twice at each tone SOA. Trial type was completely randomized. Continuous EEG was recorded during this task, too, as described next.

**Recording and Apparatus**

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. A combined push-button response box/voice key registered naming and push-button RT. The voice key recorded participants’ naming accuracy/naming RTs and the push-button response recorded tone judgement accuracy/tone judgement RTs. Tones were presented through E-A-RTone 3A (Aearo) insert earphones.

Each participant wore a nylon QuikCap (Neuroscan) fitted with 32 active recording electrodes positioned following 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-ERP Reduction**

The continuous EEG record of each participant for the dual task, and for the simple tone monitoring task, was segmented into epochs. Each epoch comprised EEG data recorded from each electrode during presentation of the tone on each trial, beginning 300 ms before and terminating 1200 ms after tone onset. Trials eliciting incorrect picture names and/or tone judgments were excluded. 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 with fast-average amplitude exceeding 200 microvolts (large drift) were marked bad, as were channels with differential amplitude exceeding 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. For the dual-task data, no fewer than 20 artifact-free trials went into the set of ERP averages for each participant in each condition. For the simple tone monitoring task, no fewer than 131 trials comprised the ERP averages in the Standard condition and no fewer than 19 trials comprised the ERP averages in the Target condition for each participant. The averaged ERP data were low-pass
filtered at a corner frequency of 40 Hz, re-referenced to averaged mastoids, truncated to the critical time window (-100 to 1000 ms), and finally baseline-corrected (-100 to 0 ms).

Analysis

Dual-task behavioral data. For the dual task, naming accuracy, naming RT, tone judgment accuracy and tone judgment RT were analyzed separately. Naming on each trial was correct if the participant used the target label within the time-out period (3000 ms). Naming was incorrect for trials eliciting no response, a whole-word substitution, a phonological error, a multi-word response, or any response after the time-out period. Tone judgment on each trial was correct if the participant withheld responding to a Standard (Low) tone or pressed the button to a Target (High) tone within the time-out period. Each set of accuracy data was submitted to a repeated-measures ANOVA with Group entered as a between-subjects variable with two levels (TFA, AWS), Distractor Type entered as a within-subjects factor with three levels (Semantic, Phonological, Unrelated), Tone Type entered as a within-subjects factor with two levels (Low, High), and Tone SOA entered as a within-subjects factor with two levels (Short, Long). Untrimmed naming RTs were also analyzed using this same approach. Untrimmed tone judgment RTs were analyzed in a repeated-measures ANOVA with Group entered as a between-subjects factor with two levels (TFA, AWS), Distractor Type entered as a within-subjects factor with three levels (Semantic, Phonological, Unrelated), and Tone SOA entered as a within-subjects factor with two levels (Short, Long). All four ANOVAs were two-sided and had an alpha-level of 0.05. For any test violating the assumption of sphericity, we report p-values based on adjusted degrees of freedom (Greenhouse & Geiser, 1959) along with original F-values. Statistically significant interactions were followed-up with Bonferroni-corrected pair-wise comparisons.
Dual-task ERP data. As discussed by Luck (1998), a challenge in measuring P3b activity in a psychological refractory period context is that ERP activity from Task 1 can overlap with ERP activity from Task 2 differently at different SOAs. His solution was to compute difference waves (Target ERPs minus Standard ERPs) separately for each Tone SOA condition in order to attenuate activity unrelated to P3. The logic of this approach is that both Target and Standard ERPs to Task 2 should be similarly influenced by overlapping Task 1 activity. Subtracting them should isolate mostly P3b activity while attenuating overlapping ERP activity from Task 1 (see Luck, 1998).

This approach was adopted. However, before computing Target minus Standard differences, the averaged ERP data were preprocessed using a covariance-based temporal principal component analysis (tPCA) (Dien & Frishkoff, 2005). PCA is a data reduction technique that can be used to facilitate objective identification of ERP components, address overlap of ERP components, and control type-1 measurement error. The aim of the tPCA was to identify distinct windows of time (hereafter, temporal factors) during which similar voltage variance was registered across consecutive sampling points in the averaged ERP waveforms. Each temporal factor is defined by a set of loadings and by a set of scores. The variance-scaled loadings describe the time-course of each temporal factor. The temporal factor scores summarize the ERP activity during the time window defined by each temporal factor for each participant, at each electrode, and in each condition. tPCA, when followed-up by topographic analysis of temporal factor scores, has been shown to optimize power for detecting statistically significant effects in ERP data sets (Kayser & Tenke, 2003; Dien, 2010).

To compute the tPCA, the averaged ERP waveforms were combined into a data matrix comprised of 501 columns (one column per time point in the 0-1000 ms epoch) and 11,520 rows
(the averaged ERP voltages for 30 participants, at each of the 32 electrodes, in each of the 12
Distractor Type-by-Tone Type-by-Tone SOA conditions). As reported below, 12 temporal
factors were retained based on the Visual Scree Test (Catell, 1966). The 12 retained temporal
factors were rotated to simple structure using Promax (Hendrickson & White, 1964) with Kaiser
normalization and k=3 (following recommendations in Richman, 1986; Tataryn, Wood, &
Gorsuch, 1999; Dien, 2010). The tPCA and Promax rotation were carried-out using the Matlab-
based PCA Toolbox (Dien, 2005).

In order to target P3 effects, a temporal factor with a time-course most consistent with
P3b was selected. As reported below, the selected temporal factor had a peak latency of 348 ms.
Filtering the averaged ERP data by this temporal factor isolated the ERP variance within a time
window peaking at ~350 ms after tone onset for each participant, at each electrode, in each
condition. To verify the presence of a P3b effect, the temporal factor scores were submitted to
repeated-measures ANOVA with Group entered as a between-subjects factor with two levels
(TFA, AWS), Distractor Type entered as a within-subjects factor with three levels (Semantic,
Phonological, Unrelated), Tone Type entered as a within-subjects factor with two levels (Low,
High), and Tone SOA entered as a within-subjects factor with two levels (Short, Long). Two
topographic factors were also included as within-subjects factors including Laterality with five
levels (Left Inferior, Left Superior, Midline, Right Superior, Right Inferior) and Anteriority with
three levels (Frontal, Central, Posterior). The 15 electrodes included for analysis were grouped
by Laterality and Anteriority as follows: F7, T7, P7 (Left Inferior); F3, C3, P3 (Left Superior);
Fz, Cz, Pz (Midline); F4, C4, P4 (Right Superior); and F8, T8, P8 (Right Inferior) (see Table 2).
The aim of this analysis was to determine whether temporal factor score amplitudes differed to
Target (High) tones versus Standard (Low) tones (i.e., had a larger positive-going amplitude to
Target versus Standard tones consistent with a P3b component) as a main effect and/or interacting with Group, Distractor Type, Tone SOA, Laterality and/or Anteriority. As reported in the Results, robust P3b effects were detected for the TFA group in all six Distractor Type-by-Tone SOA conditions. For the AWS, however, P3b effects were only detected for a subset of Distractor Type-by-Tone SOA conditions.

Next, difference scores were computed using the same set of temporal factor scores. Standard (Low) tone scores were subtracted from Target (High) tone scores, separately for each participant, in each Distractor Type, at each Tone SOA, and at each of the 15 electrodes included in the analysis. The difference scores were then submitted to repeated-measures ANOVA with Group as a between-subjects factor with two levels (TFA, AWS), Distractor Type as a within-subjects factor with three levels (Semantic, Phonological, Unrelated) and Tone SOA as a within-subjects factor with two levels (Short, Long). Laterality and Anteriority were also entered as within-subjects factors as described previously. The aim of this analysis was to determine whether the amplitude of isolated P3 effects differed as a function of Group, Condition, scalp topography or their interaction.

For both ANOVAs, we report p-values based on adjusted degrees of freedom (Greenhouse & Geiser, 1959) when necessary along with original F-values. Both ANOVAs were two-sided and had an alpha-level of 0.05. Statistically significant interactions were followed-up with Bonferroni-corrected pair-wise comparisons.

Simple oddball task behavioral data. For the simple oddball task, tone judgment accuracy and tone judgment RT were analyzed separately. Tone judgment on each trial was correct if the participant withheld responding to a Standard (Low) tone or pressed the button to a Target (High) tone within the time-out period. Tone judgment accuracy data were submitted to a
repeated-measures ANOVA with Group entered as a between-subjects factor with two levels (TFA, AWS) and Tone Type entered as a within-subjects factor with two levels (Low, High). Untrimmed tone judgment RTs were analyzed using an independent-samples t-test comparing Group (TFA versus AWS).

Simple oddball task ERP data. ERP data for the simple oddball task were also submitted to temporal PCA, following the same general procedures outlined previously. A temporal factor most consistent with the P3b component was selected. Factor scores associated with this temporal factor were analyzed in a repeated-measures ANOVA with Group entered as a between-subjects factor with two levels (TFA, AWS) and Tone Type entered as a within-subjects factor with two levels (Low, High). Laterality and Anteriority were also entered as within-subjects factors as described previously. The aim of this analysis was to determine whether temporal factor score amplitudes differed to Target (High) tones versus Standard (Low) tones as a main effect or interacting with Group and/or scalp topography. As reported in the Results, a robust P3b effect was detected for both groups. Difference scores were then computed using the same set of temporal factor scores. Standard (Low) tone scores were subtracted from Target (High) tone scores, separately for each participant at each of the 15 targeted electrodes. The difference scores were then compared between Groups using repeated-measures ANOVA with Laterality and Anteriority entered as within-subjects factors. The aim of this analysis was to determine whether the amplitude of isolated P3 effects differed as a function of Group and/or the interaction of Group and scalp topography. As reported in the Results, in contrast to P3b effects in the dual task, Group was not found to impact P3b amplitudes for the simple oddball task.
CHAPTER THREE: RESULTS

Dual Task Behavioral Data

**Naming Accuracy.** Naming accuracy was affected by the interaction of Group, Distractor Type Condition, Tone Type and Tone SOA (F(2,56) = 4, p = .03, partial eta-squared = .125). Bonferroni-corrected pairwise t-tests revealed that, for the TFA group, naming accuracy was poorer in the Phonological condition (mean = 24.27) than in the Unrelated condition (mean = 24.93) in the context of High Tones presented at a Short SOA (p = .02).

In contrast, for the AWS group, naming accuracy was poorer in the Semantic condition (mean = 24) than in the Unrelated condition (mean = 24.87) in the context of Standard (Low) Tones presented at a Long SOA (p = .003). In general, these findings reveal that naming accuracy was affected by different interactions of Distractor Type Condition, Tone Type and Tone SOA in the different groups.

**Naming RTs.** Naming RT was affected by Distractor Type Condition (F(2,56) = 83.77, p < .001, partial eta-squared = .75). Bonferroni-corrected pairwise comparisons revealed that naming RTs were slower in Semantic Distractor Type (mean = 838.78 ms) than in Unrelated (mean = 784.8 ms). In contrast, naming RTs were faster in Phonological Distractor Type (mean = 754.56 ms) versus Unrelated. The former is consistent with the standard Semantic Distractor Type effect, while the latter is consistent with the standard Phonological facilitation effect observed in previous PWI studies.
Naming RT was also affected by Tone SOA ($F(1,28) = 9.91, p = .004$, partial eta-squared = .26), with naming RTs shorter in the Short Tone SOA Condition (mean = 732.56 ms) than in the Long Tone SOA Condition (mean = 852.87 ms). As discussed later, this finding points to a possible task strategy of delaying naming when tones were not immediately presented.

Additionally, naming RT was affected by Tone Type ($F(1,28) = 16.18, p < .001$, partial eta-squared = .37), with naming RTs shorter in the context of Standard (Low) Tones (mean = 783.15 ms) than in the context of Target (High) Tones (mean = 802.27 ms). This finding tentatively suggests that hearing target tones generally delayed naming speeds.

**Button Press Accuracy.** Tone judgment accuracy was affected by Distractor Type Condition ($F(2,56) = 4.47, p = .017$, partial eta-squared = .14), with more errors in Semantic Distractor Type (mean = 24.42) than in Unrelated Distractor Type (mean = 24.62).

Accuracy in tone judgments was also affected by an interaction of Group, Tone SOA and Tone Type ($F(1,28) = 7.72, p = .01$, partial eta-squared = .22). Bonferroni-corrected t-tests revealed that TFA had less accurate tone judgments for Target (High) tones (mean = 24.27) than for Standard (Low) tones (mean = 24.8) at the Long Tone SOA. In contrast, AWS had less accurate tone judgments for Target (High) Tones (mean = 24.07) than for Standard (Low) tones (mean = 24.62) at the Short Tone SOA.

**Button Press RTs.** Tone judgment RT was affected by Distractor Type Condition ($F(2,56) = 13.82, p < .001$, partial eta-squared = .33), with tone judgments slower in Semantic Distractor Type (mean = 656.79 ms) than in Unrelated Distractor Type (mean = 621.63 ms).
Tone judgment RT was also affected by Tone SOA (F(1,28) = 263.65, p < .001, partial eta-squared = .9), with tone judgments slower at the Short Tone SOA (mean = 751.05 ms) than at the Long Tone SOA (mean = 518.6 ms).

**Dual-Task ERP Data**

Grand average ERP waveforms are shown for each Group, at three midline electrodes, for each Tone Type, separately for each Distractor Type-by-Tone SOA combination in Figures 2 through 7, respectively. As shown in these figures, the tones generally elicited a pattern of early (exogenous) ERP activity followed by later positive-going activity often modulated by Tone Type, particularly at electrode Pz. This Tone Type effect appeared to be attenuated in at least some Distractor Type-by-Tone SOA conditions for the AWS group.

The temporal PCA resulted in 12 Promax-rotated temporal factors, accounting for 80.79% of the variance in the average ERP data set. One temporal factor was defined by a set of loadings that peaked in amplitude at 348 ms after tone onset (hereafter, T348, see Figure 8). T348 factor scores were affected by an interaction of Group, Distractor Type, Tone Type, Tone SOA, Laterality and Anteriority (F[16,448]=2.01, p=.047). Figure 9 depicts grand average T348 scores topographically.

Bonferroni-corrected pairwise t-tests revealed that, for the TFA, T348 scores to Target (High) tones had a larger positive-going amplitude than T348 scores to Standard (Low) tones in each Distractor Type-by-Tone SOA condition at electrode Pz (p<=.01). Table 2 lists the other electrodes at which a significant Target versus Standard difference was also detected (p<.05) in the TFA in each Distractor Type, at each Tone SOA.

The AWS, T348 scores to Target (High) tones had a larger positive-going amplitude than
Table 1
Mean accuracy and RTs (with standard deviations) for each group during each naming condition.

<table>
<thead>
<tr>
<th>Group</th>
<th>TFA</th>
<th>AWS</th>
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<tbody>
<tr>
<td><strong>Naming Accuracy (n = 25 items per condition) in Tone (Standard) Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tone SOA</strong></td>
<td>Short (50 ms)</td>
<td>Long (900 ms)</td>
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<tr>
<td>Semantic</td>
<td>24.13 (1.41)</td>
<td>24.27 (1.03)</td>
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<tr>
<td>Phonological</td>
<td>24.67 (0.62)</td>
<td>24.87 (0.35)</td>
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<tr>
<td>Unrelated</td>
<td>24.6 (0.63)</td>
<td>24.8 (0.41)</td>
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<tr>
<td><strong>Naming Accuracy (n = 25 items per condition) in Tone (Target) Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tone SOA</strong></td>
<td>Short (50 ms)</td>
<td>Long (900 ms)</td>
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<td>24.27 (1.03)</td>
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<td><strong>Naming RT (in ms) in Tone (Standard) Type</strong></td>
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<tr>
<td><strong>Tone SOA</strong></td>
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<td>Long (900 ms)</td>
</tr>
<tr>
<td>Semantic</td>
<td>776.74 (79.73)</td>
<td>861.1 (242.74)</td>
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<tr>
<td>Phonological</td>
<td>681.43 (82.24)</td>
<td>795.27 (285.73)</td>
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<tr>
<td>Unrelated</td>
<td>716.08 (66.31)</td>
<td>827.56 (265.71)</td>
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<tr>
<td><strong>Naming RT (in ms) in Tone (Target) Type</strong></td>
<td></td>
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<tr>
<td><strong>Tone SOA</strong></td>
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<td>Long (900 ms)</td>
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<td>887.75 (274.63)</td>
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<td>819.98 (287.71)</td>
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<tr>
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<td>729.31 (97.47)</td>
<td>834.51 (292.13)</td>
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<td><strong>Button Press Accuracy (n = 25 items per condition) in Tone (Standard) Type</strong></td>
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<td>24.8 (0.41)</td>
</tr>
<tr>
<td><strong>Button Press Accuracy (n = 25 items per condition) in Tone (Target) Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tone SOA</strong></td>
<td>Short (50 ms)</td>
<td>Long (900 ms)</td>
</tr>
<tr>
<td>Semantic</td>
<td>24.4 (0.74)</td>
<td>24.07 (1.1)</td>
</tr>
<tr>
<td>Phonological</td>
<td>24.73 (0.59)</td>
<td>24.2 (0.94)</td>
</tr>
<tr>
<td>Unrelated</td>
<td>24.6 (0.83)</td>
<td>24.53 (0.64)</td>
</tr>
<tr>
<td><strong>Button Press RT (in ms) in Tone (Standard) Type: Results are not applicable as this portion of the task was an inhibitory response.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tone SOA</strong></td>
<td>Short (50 ms)</td>
<td>Long (900 ms)</td>
</tr>
<tr>
<td>Semantic</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Phonological</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Unrelated</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Button Press RT (in ms) in Tone (Target) Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tone SOA</strong></td>
<td>Short (50 ms)</td>
<td>Long (900 ms)</td>
</tr>
<tr>
<td>Semantic</td>
<td>802.69 (195.97)</td>
<td>566.3 (203.42)</td>
</tr>
<tr>
<td>Phonological</td>
<td>756.38 (173.79)</td>
<td>532.28 (208.53)</td>
</tr>
<tr>
<td>Unrelated</td>
<td>768.41 (175.85)</td>
<td>528.54 (181.62)</td>
</tr>
</tbody>
</table>
T348 scores to Standard (Low) tones for four of the six Distractor Type-by-Tone SOA conditions at electrode Pz (p<.05). A Tone Type effect was not detected for AWS at Pz for the Phonological Distractor+Short SOA condition (p=.48) or for the Unrelated Distractor+Short SOA conditions (p=.09). Nor was a Tone Type effect detected for these two conditions at any of the other electrodes. Table 2 lists the electrodes at which a significant Target versus Standard difference was detected (p<.05) in each Distractor Type, at each Tone SOA.

Inspection of Figure 9 suggests that T348 scores may have differed between Groups in each Tone Type. To investigate this possibility, T348 scores were compared between Groups separately for each Tone Type, in each Distractor Type, at each Tone SOA. T348 scores were shown to be larger in amplitude for the AWS versus TFA, in the Semantic Distractor+Standard Tone+Short SOA condition, at electrode P3 (p=.043) and, marginally, at electrode Pz (p=.08). T348 scores were also shown to be marginally larger in amplitude for the AWS versus TFA, in the Unrelated Distractor+Standard Tone+Short SOA condition at electrodes Cz (p=.06) and C4 (p=.09).

Next, we analyzed Difference scores (Target minus Standard) to determine whether detected P3 effects differed in magnitude between Groups as a function of Distractor Type and Tone SOA. The Difference scores were shown to be affected by an interaction of Group, Distractor Type, Tone SOA, Laterality and Anteriority (F[16,448]=2.01, p=.047). Bonferroni-corrected t-tests, comparing Group at electrode Pz for each Distractor Type-by-Tone SOA combination, revealed attenuated Difference score amplitudes for AWS versus TFA in the Semantic Distractor+Short SOA (p=.038), Phonological Distractor+Short SOA (p=.026), and Unrelated Distractor+Long SOA (p=.018) conditions. Table 2 shows other electrodes at which Difference scores were significantly attenuated (p<=.05) in AWS versus TFA.
Table 2
Table of electrodes at which a significant effect was detected listed by anteriority and laterality.

<table>
<thead>
<tr>
<th>TFA</th>
<th>Distractor Type</th>
<th>Tone SOA</th>
<th>Right Inferior</th>
<th>Right Superior</th>
<th>Middle</th>
<th>Left Superior</th>
<th>Left Inferior</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Semantic</td>
<td>Short</td>
<td>T7, P7</td>
<td>C3, P3</td>
<td>Fz, Cz, Pz</td>
<td>C4, P4</td>
<td>T8, P8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>P7</td>
<td>C3, P3</td>
<td>Pz</td>
<td>P4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>Short</td>
<td>T7, P7</td>
<td>F3, C3, P3</td>
<td>Fz, Cz, Pz</td>
<td>C4, P4</td>
<td>P8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>T7, P7</td>
<td>C3, P3</td>
<td>Cz, Pz</td>
<td>C4, P4</td>
<td>T8, P8</td>
</tr>
<tr>
<td></td>
<td>Unrelated</td>
<td>Short</td>
<td>P7</td>
<td>P3</td>
<td>Cz, Pz</td>
<td>C4, P4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>T7, P7</td>
<td>F3, C3, P3</td>
<td>Fz, Cz, Pz</td>
<td>F4, C4, P4</td>
<td>T8, P8</td>
</tr>
<tr>
<td>AWS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semantic</td>
<td>Short</td>
<td></td>
<td></td>
<td>Cz, Pz</td>
<td>P4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>T7, P7</td>
<td>C3, P3</td>
<td>Cz, Pz</td>
<td>C4, P4</td>
<td>P8</td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>Short</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>P7</td>
<td>P3</td>
<td>Pz</td>
<td>P4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unrelated</td>
<td>Short</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td>T7, P7</td>
<td>F3, C3, P3</td>
<td>Fz, Cz, Pz</td>
<td>F4, C4, P4</td>
<td>P8</td>
</tr>
<tr>
<td>AWS vs. TFA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semantic</td>
<td>Short</td>
<td></td>
<td>P3</td>
<td>Pz</td>
<td>P4</td>
<td>P8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>Short</td>
<td>P7</td>
<td>C3</td>
<td>Pz</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unrelated</td>
<td>Short</td>
<td></td>
<td>P7</td>
<td>P3</td>
<td>Pz</td>
<td>P4</td>
</tr>
</tbody>
</table>
Figure 1
The electrode array used to record ERPs.
Figure 2
Grand average waveforms for TFA and AWS in the semantic priming condition at the short SOA (50 ms) at Fz, Cz, and Pz.
Figure 3
Grand average waveforms for TFA and AWS in the semantic priming condition at the long SOA (900 ms) at Fz, Cz, and Pz.
Figure 4
Grand average waveforms for TFA and AWS in the phonological priming condition at the short SOA (50 ms) at Fz, Cz, and Pz.
Figure 5
Grand average waveforms for TFA and AWS in the phonological priming condition at the long SOA (900 ms) at Fz, Cz, and Pz.
Figure 6
Grand average waveforms for TFA and AWS in the unrelated priming condition at the short SOA (50 ms) at Fz, Cz, and Pz.
Figure 7
Grand average waveforms for TFA and AWS in the unrelated priming condition at the long SOA (900 ms) at Fz, Cz, and Pz.
Figure 8
Temporal factor loadings for the Dual Task.
Figure 9
Topographic plots of averaged amplitudes using T348 at each electrode site for TFA and AWS during the Dual Task.
Simple Oddball

**Button Press Accuracy.** Tone judgment accuracy was not affected by Group, Tone Type or their interaction.

**Button Press RTs.** Tone judgment RT was marginally affected by Group (t(28) = 1.79, p = .08), with tone judgments faster for AWS (mean = 323.98 ms) than for TFA (mean = 365.63 ms).

**Simple Oddball ERP Data**

Simple oddball task grand average ERP waveforms are shown for each Group, at three midline electrodes, in Figure 10. As shown, the tones generally elicited a pattern of early (exogenous) ERP activity followed by later positive-going activity modulated by Tone Type, particularly at electrode Pz.

The temporal PCA resulted in 14 Promax-rotated temporal factors, accounting for 84.10% of the variance in the simple oddball average ERP data set. One temporal factor was defined by a set of loadings that peaked in amplitude at 312 ms after tone onset (hereafter, T312, see Figure 11). The T312 factor scores were affected by an interaction of Laterality, Anteriority and Tone Type (F[8,224]=5.84, p =.003). As shown in Figure 12, T312 scores had a larger positive-going amplitude to Target versus Standard tones in both Groups, primarily at posterior electrodes. Group did not affect T312 amplitudes, either as a main effect or interacting with Laterality, Anteriority and/or Tone Type.

As with the dual-task data, here Difference scores were also analyzed (Target minus Standard) to determine whether detected P3b effects differed in magnitude between Groups. The Difference scores were shown not to be affected by Group, either as a main effect or interacting with Laterality and/or Anteriority.
Table 3
Mean accuracy and RTs (with standard deviations) for each group during the Simple Oddball Task.

<table>
<thead>
<tr>
<th>Groups</th>
<th>TFA</th>
<th>AWS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Button Press Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard (n = 144 items)</td>
<td>143.67 (0.82)</td>
<td>143.6 (0.91)</td>
</tr>
<tr>
<td>Target (n = 36 items)</td>
<td>35.93 (0.26)</td>
<td>35.87 (0.35)</td>
</tr>
<tr>
<td><strong>Button Press RTs (in ms)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target</td>
<td>365.63 (48.54)</td>
<td>323.98 (75.99)</td>
</tr>
</tbody>
</table>
Figure 10
Grand average waveforms for TFA & AWS at Fz, Cz, and Pz in the Simple Oddball Task.
Figure 11
Temporal factor loadings for the Simple Oddball Task.
Figure 12
Topographic plots of averaged amplitudes using T312 at each electrode site for TFA and AWS during the Simple Oddball Task.
CHAPTER FOUR: DISCUSSION

The aim of this study was to investigate how AWS allocate attentional resources during a 1) linguistic task and 2) when linguistic demands are absent. To investigate these aims, 15 TFA and 15 AWS completed a dual-task in which they judged two tone types (standard (800 Hz) tone and target (1000 Hz) tone), pressing a button when they heard the Target (High) tone. Nearly simultaneously, participants named pictures while ignoring printed distractor words. Distractor words were either Semantically related (Picture of apple vs. distractor word peach), Phonologically related (Picture of apple vs. distractor word apparel) or Unrelated (Picture of apple vs. distractor word truck). To investigate attentional allocation without linguistic demands present, AWS and TFA additionally completed a simple auditory oddball task. In that task, participants judged two tone types (Standard (800 Hz) tone and Target (1000 Hz) tone) and pressed a button when they heard the Target (High) tone. Behavioral and brain electrophysiological data recorded during both tasks were analyzed. The amplitude of the P3b component was measured as an index of attentional allocation during linguistic (Dual-Task) and non-linguistic (Simple Oddball) task processing (Luck, 1998; Dien, Spencer & Donchin, 2004).

Dual-Task Behavioral Results

For the dual task, we sought to replicate Ferreira and Pashler (2002) by demonstrating that both naming times and tone judgment times were slower in the Semantic Distractor condition. This effect was replicated, suggesting that the antecedent conditions present in the current dual task at least approximated those observed in Ferreira and Pashler (2002).
In both groups, naming RTs were affected by Distractor Type Condition. Naming RTs were slower in the Semantic Distractor Type than in the Unrelated condition. In contrast, the naming RTs were faster in the Phonological Distractor Type than in the Unrelated condition. This finding is consistent with Ferreira and Pashler (2002), where TFA were observed to have slower naming during the semantic condition (the standard Semantic Interference Effect) and faster naming when word-forms were related phonologically (the standard Phonological Facilitation Effect). As they explain, when two words share semantic properties (e.g., both words presented are fruit), many concepts are activated within the mental lexicon. This, in turn, creates competition in lemma selection and, ultimately, slowed naming RTs. Conversely, when phonological word-forms are related, competition in lemma selection is reduced and phonological overlap facilitates phonological word-form selection, thus shortening naming RTs.

For both groups, tone judgement RTs were also slower in the Semantic Distractor Type than in the Unrelated Distractor Type, particularly at the Short Tone SOA. This finding is consistent with Ferreira and Pashler (2002). The combination of a) prolonged naming RTs with Semantic Distraction, and b) prolonged tone judgment RTs in the context of Semantic Distraction was interpreted by Ferreira and Pashler (2002) as suggesting that lexical-semantic processing in picture naming bottlenecks with central processing of tones.

Several other RT effects were additionally observed. Naming RTs were shorter in the Short SOA than the Long SOA. This finding suggests that groups may have utilized a strategy in which they delayed naming when tones were not immediately presented. Perhaps participants delayed naming when they did not hear the tones immediately (50 ms following stimulus onset), anticipating a Long SOA and providing them additional time to resolve naming competition.
Additionally, naming RTs were shorter in the presence of Standard (Low) tones than in Target (High) tones. As described previously, participants were instructed to name the target word and then press a button in response to a Target (High) tone. Therefore, it is possible that naming during a Target (High) tone would take longer for the participants to complete, as they were occupied by preparing lemma selection and/or phonological word-from selection, categorizing the auditory stimulus, resolving production processes and then pressing the response-button.

In addition to RT effects, several accuracy effects were observed too. In TFA, naming accuracy was poorer in the Phonological Distractor Type+Target Tone Type+Short SOA than in the Unrelated Distractor Type+Target Tone Type+Short SOA condition. A possible explanation for this result may be found in Roelofs (2008), who posits that during speech production, auditory processing is suppressed and in a dual task paradigm (Task 1 naming, Task 2 auditory) Task 1 can hamper Task 2 performance. Strategically, attention may be shifted to Task 2 earlier. As a result, there would be more errors in the Phonological Distractor Type condition as attention shifts prematurely to Task 2. These results are not consistent with Ferreira and Pashler (2002), who reported that TFA demonstrated poorer naming accuracy in the Semantic Distractor Type in the context of all Tone SOAs and Distractor SOAs.

Conversely, AWS in the current task demonstrated poorer naming accuracy in the Semantic Distractor Type+Standard Tone Type+Long SOA than in the Unrelated Distractor Type+Standard Tone Type+Long SOA condition. Significant errors in naming were not detected in other conditions. This may be due to lack of maintenance of the word from in short-term memory storage. In other words, AWS may have maintained the wrong word-form in their mental lexicon in the context of the Standard (Low) tone at the Long SOA.
Both groups had less accurate tone judgements in the Semantic Distractor Type than in the Unrelated Distractor Type. This finding is consistent with Ferreira and Pashler (2002), who posited that more tone judgement errors were made in the semantic condition due to the intense demands of response selection posed by lemma retrieval. Furthermore, TFA had less accurate tone judgements for Target (High) tones than for Standard (Low) tones at the Long SOA. AWS had less accurate tone judgements for Standard (Low) tones than Target (High) tones at the Short SOA. These findings suggest that perhaps TFA may have been more sensitive to the Standard (Low) tones and AWS may have been more sensitive to Target (High) tones. Another possible explanation may be that TFA were allocating more attentional resources toward maintaining the word form in their short term memory during the Long SOA and therefore did not have resources left over to accurately categorize the auditory stimulus. Alternatively, AWS still may have been resolving response-selection demands at the Short SOA and therefore judged tones less accurately.

**Dual-Task ERP Results for TFA**

The primary aim of the dual task was to determine whether a P3b effect could be detected at each Tone SOA in each Picture-Word Distractor condition. For the TFA, P3b was detected at both Tone SOAs in all three Picture-Word Distractor conditions. Differences were observed in the scalp topographies of P3b effects, as outlined herein. In general, different scalp topographies may suggest that different neural sources were involved in generating P3b effects in the different Tone SOA by Distractor Type conditions and/or that the same neural resources were involved in generating P3b effects but activated to different degrees in the different Tone SOA by Distractor Type conditions (Alain, Achim & Woods, 1999).
TFA always demonstrated a topographically widespread positivity peaking at 348 ms after Target tone onset, which we associated with P3b activation. This time course is consistent with P3b latencies reported in other dual task literature (Luck, 1998; Dell’Acqua et al., 2005). In the Semantic Distractor Type condition at the Short SOA, a widespread P3 effect was observed for TFA. With respect to anteriority, TFA evidenced a robust P3 effect that was detected at Fz, midline electrodes, and especially at posterior electrodes (including Pz). Furthermore, P3b laterality effects were detected at the inferior left, superior left, midline, superior right, and inferior right electrode sites. During the Semantic Distractor Type at the Long SOA, a P3 effect was detected but it was not as widespread as the Semantic Distractor Type condition at the Short SOA. This effect was primarily restricted to the posterior region of the scalp, suggesting fewer attentional resources were available to detect the Target (High) tone type.

In the Phonological Distractor Type condition at the Short SOA, there was again a topographically-widespread P3 effect detected. The Phonological Distractor Type condition at the Long SOA results greatly resembled those of the Semantic Distractor Type condition at the Long SOA. Significant P3 effects were identified at posterior and central electrode sites. This again suggests that TFA may have had fewer attentional resources to allocate in the detection of the Target (High) tone. A possible explanation could be that at the Long SOA for both the Semantic and Phonological Distractor Type, TFA experienced more task inference effects between Task 1 and Task 2 which resulted in a posterior-spread activation topographically.

In the Unrelated Distractor Type condition at the Short SOA significant P3 effects were identified, primarily, at posterior electrode sites. This suggests that TFA recruited different neural sources than during the other Distractor Type conditions to detect the Target (High) tone at the Short SOA. This could be due to the nature of linguistic processing when presented.
unrelated word-forms while categorizing tone type. Conversely, at the Long SOA more widespread activation of the P3 effect was detected; specifically, at left/mid/right and anterior/central/posterior electrode sites.

Ferreira and Pashler (2002) proposed a model of word production in three stages. First, the speaker experiences pre-word production processes in which they perceive the stimuli. Secondly, the speaker then engages in central processing which includes 1) lemma selection, 2) phonological word-form selection and 3) phoneme selection. Finally, the speaker engages in post-word production processes in which they execute the intended word-form. The central-bottleneck effect reviewed in the study states that as speakers engage in the second (or central) stage of this model, they must resolve lemma selection, phonological word-form selection and phoneme selection before progressing to the final stage of the model, post-word production.

According to the proposed model, a P3 effect could be measured, with perhaps some overlap, between Task 1 (naming) and Task 2 (auditory). The salience of these effects would depend on the tone SOA, as some resolution of naming is expected to occur before Task 2 commences. In the present study, TFAs demonstrated a constant presence of a P3 effect indicating that during linguistic processing, there were sufficient attentional resources to allocate towards the perception and categorization of auditory stimuli, following linguistic processing.

**Dual-Task ERP Results for AWS**

In contrast to the TFA, a robust P3 effect was not observed for AWS in some Distractor Type-by-Tone SOA conditions. Furthermore, when P3 effects were detected for AWS, they were sometimes attenuated in amplitude relative to TFA.
AWS demonstrated a relatively local P3 effect detected only at Cz, Pz and P4 electrodes during the Semantic Distractor Type at the Short Tone SOA. Furthermore, even though P3 activation was detected at these electrodes for AWS, the amplitude of this effect was smaller versus P3 amplitude at these same electrodes in TFA. This result suggests that, for AWS, resolving Semantic competition was particularly attentionally demanding versus TFA. Conversely, a topographically-widespread P3 activation was detected in the Semantic Distractor Type at the Long SOA. As the tone was presented at the longer latency, the resolution of semantic competition probably allowed more attentional resources to be allocated towards categorization of the tone stimuli.

During the Phonological Distractor Type at the Short SOA, a P3 effect was not detected statistically at any electrode for the AWS. One interpretation is that, for AWS, resolving phonological competition is so attentionally-demanding as to severely draw attentional resources away from tone categorization. During the Phonological Distractor Type at the Long SOA, P3 effects in AWS were detected but were limited to the P3, Pz and P4 electrodes. This implies that, even at the Long Tone SOA, AWS still allocated significant attentional resources toward phonological processing, perhaps due to prolonged difficulty resolving phonological competition and/or maintaining the target word in phonological memory for overt naming.

Finally, a P3 effect was not detected in AWS during the Unrelated Distractor Type at the Short SOA. However, a widespread P3 effect was detected in Unrelated Distractor at the Long SOA. It could be that AWS required longer SOAs to resolve naming of unrelated distractor and target labels in order to respond to tone types.

These results suggest that AWS utilize more cognitive resources than TFA to resolve competition during lexical retrieval. This provides further support that lexical retrieval is
atypically attentionally-demanding in AWS. As reviewed in the Introduction, AWS evidenced anomalous ERP activity in other picture naming tasks, with those ERP effects pointing to atypical attentional control during lexical retrieval. An important question is whether this was due to limited attentional capacity. To rule-out this possibility, we also investigated P3 effects in AWS versus TFA in a simple tone oddball task.

**Simple Oddball Task Behavioral and ERP Results**

In the current study, there were not any robust behavioral or P3 effects that differentiated TFA and AWS. The AWS did trend toward faster tone judgment times, and visual inspection of the ERP data is suggestive of slightly attenuated P3 amplitudes in AWS versus TFA, perhaps reflecting greater individual variation in the AWS group. This finding is in accordance with Sassi and colleagues (2011). The authors reported that there were no significant P3 differences identified between groups; however, there were marked individual differences in the AWS group. Hampton and Weber-Fox (2008), upon visual inspection and using peak-to-peak amplitude analysis, found a subgroup of AWS that demonstrated attenuated P3 amplitudes.

Upon visual inspection, there appears to be subtle differences in topographic distribution of P3 between AWS and TFA. However, there were not any significant differences detected between groups, with respect to anteriority and laterality. These results contrast with Morgan, Cranford, and Burke (1997), who reported significant differences in the scalp topography of P3 effects in TFA versus AWS. Specifically, 5 out of the 8 AWS demonstrated greater P3 amplitudes over the left hemisphere, whereas the TFA had greater P3 amplitudes over the right hemisphere. Overall, the current simple oddball P3 effects coincide with other studies in which P3 was not shown to differ in morphology in AWS versus TFA (Blomgren et al., 2012; Sassi et al., 2011; Morgan, Cranford & Burke, 1997; Ferrand et al., 1991; Khedr et al., 2000; Hampton &
Weber-Fox, 2008). With this in mind, the P3 decrements seen in AWS in the dual task cannot be attributed to attentional capacity deficits but, rather, suggest that AWS allocate attentional resources differently during lexical retrieval.

**Study Limitations and Future Directions**

A limitation to the current study included an uneven sex distribution between groups. There were more females in the TFA and more males in the AWS group. According to Conroy and Polich (2007), typically fluent females demonstrate attenuated P3 effects when compared to typically fluent males. However, this did not seem to affect the P3 results presented in the current study as the AWS group demonstrated attenuated P3 effects and not vice-versa. Perhaps a male sex-matched group of TFA would have shown greater amplitudes, thus detecting significant attenuated effects from the AWS in more Distractor Type conditions.

It is hypothesized that AWS may have an impaired working memory system (see Bajaj, 2007). The theory of the P3 wave is that it is an indexed reflection of the processes associated with updating working memory (Donchin, 1981; Luck, 1998). As reported by Luck (1998), interference between two tasks can dampen P3 effects. Dual-task interference occurs sometime between the sensory and motor execution stages. Furthermore, sources of this interference can be possibly attributed to a delay in the processing of Task 1 due to the incoming information from Task 2. These effects were observed in the current study. It is still unclear how AWS would perform in a non-linguistic dual-task. The literature lacks evidence to determine whether word retrieval is uniquely demanding attentional resources, or whether any dual-task would disproportionately allocate attentional resources in AWS. Graded effects were observed, which suggests different stages of word retrieval are more or less cognitively demanding. Still, it cannot be ruled-out that general dual-tasking demands greater attentional resources in AWS.
A cross-modal task was used in the current study. Task 1 was a visual word overlay and Task 2 was an auditory categorization task of a Standard (Low) tone and a Target (High) tone. There is currently some discussion about whether auditory monitoring is impaired in AWS. Several structural brain abnormalities have been reported in AWS that indicate stuttering may result from deficits in the processing of sensorimotor integration that are crucial for early and mature speech motor control (Daliri and Max, 2015; Beal et al., 2010; Brown et al., 2005; Cai et al., 2012; Chang et al., 2011; Max, 2004). Daliri and Max (2015) reported that AWS did not demonstrate typical auditory evoked potentials, suggesting that stuttering may be associated with deficits in the modulation of auditory stimuli during linguistic tasks. Roelofs (2008) reported that intra-modal tasks have yielded different behavioral results for phonological encoding in TFA. Consequently, the presence of dual-task interference from phonological encoding depends on the modality of the unrelated secondary task. Specifically, in context of the current study, the Phonological Distractor Type condition may have yielded different results if Task 2 was different. To date, there is one study in which Khedr and colleagues (2000) examined ERP effects of stutterers using multi-modal stimuli. Results detected a significant reduction in amplitude of P100 of visual evoked potentials, and no significant abnormalities were recorded in P200, N200 and P300 of event-related potentials in stutterers compared with the control group. It would be interesting to run a visual-only dual-task, in the interest of replication, which may yield alternate results in the TFA and AWS groups.

An important question to consider is: If lexical retrieval demands unusual attention in AWS, how might this ultimately impact fluency? Results of this study suggest attention is drawn away from auditory monitoring. Unknown is whether, does lexical retrieval draws attention away from (near-) concurrent speech motor readiness in the same way. Maxfield and colleagues are
currently developing a procedure for investigating the speech motor readiness potential (see Wohlert, 1993) under easier versus more difficult language processing demands, with an ultimate eye toward testing language-motor interaction in AWS.

Another question that arises is whether implementation of attentional training might be beneficial as part of intervention for stuttering? Currently, attentional training that is used in stuttering intervention focuses on cognitive behavior therapy (CBT). It is used widely with adults and children to help improve mindfulness. It is claimed that by increasing one’s attention to cognitive reactions, an individual can control where they direct their attention and reduce negative thought patterns. In other words, CBT involves directing attention to productive thought patterns and inhibition of attention to negative thought patterns, and in that sense this is attentional training. The greater the attentional control, the greater the reduction of negative thought patterns (Menzies et al., 2008).

Menzies and colleagues (2008) conducted a systematic review of the literature concerning AWS and cognitive behavior therapy (CBT). CBT is an intervention developed from the fields of clinical psychology and psychiatry. It has several components including cognitive restructuring, behavioral experiments and attentional training. The authors compiled studies that used comprehensive CBT programs in conjunction with elements of speech treatment for AWS. One study, Blood (1995), used “a commercially available computer-assisted feedback program” for reducing disfluencies with a relapse management program. The program contained many elements of executive functioning skills including problem solving, cognitive restructuring/reframing and non-directive supportive counseling using visual and auditory stimuli. It was reported that all AWS demonstrated significant gains in fluency post-test and at a one-year follow up. However, it was concluded that the results obtained from the study could not
provide conclusive evidence of efficacy regarding attentional training because all participants received the same program and there was no control group. Menzies and colleagues (2009) concluded that further research is needed regarding attentional training to determine its efficacy as an intervention strategy for AWS.

More recently, attentional training was shown to improve fluency in pre-teens who stutter. Thirty pre-teens with developmental stuttering participated in NEurocognitive Joyful Attentive Training Intervention (NEJATI) over 12 sessions (Nejati, Poretemad and Bahrami, 2013). NEJATI is a computer based program that is comprised of four tasks. The tasks are graded and increase in difficulty as trainees master techniques. Tasks included sorting stimuli that were visually presented; rules for sorting changed as task accuracy increased. The study resulted in significant reduction of stuttering with attention training. These results, again, suggest that attentional training may benefit people who stutter. Unknown is whether these training programs have the effect of stabilizing lexical retrieval, speech motor and/or other processes involved in producing speech.

**Summary and Conclusion**

The results of the present study suggest that when compared to TFA, AWS demonstrated attenuated P3 effects in a tone categorization task that was nearly simultaneous with a picture-word interference task. In certain Distractor Type conditions, P3 effects were undetectable in AWS while, in other conditions, they were detected but attenuated in amplitude relative to TFA. These results tentatively suggest AWS allocate attentional resources to processes in lexical retrieval. It is important to note that in the Simple Oddball task, AWS generated similar P3 effects as TFA. This implies that in the absence of linguistic demands AWS allocated attentional resources similarly to TFA when processing auditory tone stimuli.
Possible clinical implications include a better understanding of the deficits concerning developmental stuttering. If AWS allocate attentional resources differently than TFA during lexical access, motor based therapies may not be sufficient and relapse could occur without addressing inefficient lexical retrieval abilities in addition to motor decrements that are often associated with stuttering. One approach could be to use attentional training to aid AWS in allocating cognitive resources optimally in complex tasks such as in speech production. Probing working memory skills during assessment could provide an idea of stimulability for attentional training and inform treatment planning.

Until the role of attentional training in stuttering intervention is better understood, it is important to consider the impact of current interventions on language and cognitive processing in AWS. Two evidence-based approaches to treatment of adulthood stuttering are Stuttering Management and Fluency Shaping. In Stuttering Management, the aim is to teach the client to stutter without unnecessary avoidance behaviors, tension or struggle. In Fluency Shaping, the aim is to teach the client to stutter less frequently. The latter is often preferred by Speech-Language Pathologists and by clients, even though there is evidence that relapse is likely if avoidance and struggle behaviors are not addressed as part of intervention for stuttering. In Stuttering Management, clients learn to eliminate avoidance behaviors commonly used to mask stuttering including linguistic avoidance behaviors (e.g., word substitutions, circumlocutions, retrials). In principle, reducing atypical usage of the mental lexicon should stabilize lexical retrieval in AWS. Evidence from the current study and other cited research provides at least indirect support for the idea that stabilizing lexical retrieval should be a target of intervention for stuttering in addition to the usual focus on speech motor control.
REFERENCES


APPENDIX A: IRB LETTER OF DETERMINATION

May 18, 2010

Nathan Maxfield,
Communication Sciences and Disorders
4202 East Fowler Avenue, PCD1017

RE: Expedited Approval for Initial Review
IRB #: Pro00001111
Title: Picture Naming Electrified: Brain Electrophysiological Correlates of Psycholinguistic Planning in Adults who Stutter

Dear Nathan Maxfield:

On 5/17/2010 the Institutional Review Board (IRB) reviewed and APPROVED the above referenced protocol. Please note that your approval for this study will expire on 5-17-11.

Approved Items:
Protocol Document(s):

Maxfield_L_R03_DC011144-01[31].pdf 4/29/2010 12:53 PM 0.01

Please note for the future, IRB review occurs after you have received your grant approval/funding.

Consent/Assent Document(s):

Informed Consent.pdf 5/18/2010 9:06 AM 0.01

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45 CFR 46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:

(4) Collection of data through noninvasive procedures (not involving general anesthesia or
sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing.

(6) Collection of data from voice, video, digital, or image recordings made for research purposes.

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Please note, the informed consent/assent documents are valid during the period indicated by the official, IRB-Approval stamp located on the form. Valid consent must be documented on a copy of the most recently IRB-approved consent form.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-9343.

Sincerely,

Krista Kutash, PhD, Chairperson
USF Institutional Review Board

Cc: Various Menzel, CCRP
    USF IRB Professional Staff