The Dissertation Committee for Geoffrey Austin Coalson Certifies that this is the approved version of the following dissertation:

Silent Phoneme Monitoring of Nonwords in Adults Who Do and Do Not Stutter

Committee:

Courtney T. Byrd, Supervisor

Thomas P. Marquardt

Harvey M. Sussman

Randy L. Diehl

Michael J. Mahometa

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by

Geoffrey Austin Coalson, BA; BS-CSD; MS

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To my wife

Who has provided loving support and positive feedback

Throughout all my many iterations

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Silent Phoneme Monitoring of Nonwords in Adults Who Do and Do Not Stutter

Geoffrey Austin Coalson, PhD
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Supervisor: Courtney T. Byrd

Stuttering has been attributed, at least in part, to subclinical differences in phonological encoding. The present study is comprised of two experiments designed to explore the role of stress, a metrical aspect of phonological encoding, during silent phoneme monitoring. For Experiment 1, participants who do and do not stutter were required to nonverbally monitor target phonemes in nonwords with initial stress. For Experiment 2, an additional group of typically fluent and stuttering participants were required to monitor phonemes in nonwords with non-initial stress thereby forcing them to first monitor the syllable boundary. Results indicated that similar to segmental information, processing metrical information requires additional time in adults who stutter. Theoretical and clinical implications of these findings are discussed.

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Chapter 1: Introduction

Stuttering is a disorder that affects approximately 1% percent of the adult population (almost 3 million people) and can impose potentially negative academic, vocational, and societal consequences (for WHO-ICF description, see Yaruss & Quesal, 2004). The observable properties of stuttering include atypical disruptions in the forward momentum of speech, characterized by sound repetitions (e.g., “b-b-b-backpack”), syllable repetitions (e.g., “back…back…backpack”), monosyllabic word repetitions (e.g., “my...my…my… my backpack), audible sound prolongations (e.g., “mmmmmmy backpack), and/or inaudible blocks (e.g., “[b] ------ backpack”; Yairi & Ambrose, 2005). Multiple theoretical models of stuttering attribute this difficulty in establishing and/or maintaining fluent speech to disruptions that occur during *phonological encodin*g, the level of speech planning that occurs prior to phonetic programming and overt articulation (e.g., Byrd, Conture, & Ohde, 2007; Howell, 2011; Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993; Vasic & Wijnen, 2005; Wingate, 1988).

According to Levelt and colleagues’ model of speech production (Levelt, 1989; Levelt, Roelofs, & Meyer, 1999), phonological encoding generates an abstract speech plan by retrieving and re-combining two types of information prior to overt production: segmental properties (i.e., the sounds within a word) and metrical properties (i.e., syllable stress and syllable boundary assignment). Levelt et al. posit both segmental and metrical properties are necessary during rapid phonological encoding in adults and that both properties can delay the timely processing of the preverbal speech plan.

A large body of both experimental and descriptive data demonstrate the *segmental* aspect of phonological encoding is compromised in children and adults who stutter (e.g., Anderson, 2007; Anderson & Byrd, 2008; Bosshardt, 1993; Byrd, Conture, & Ohde, 2007; Byrd, Vallely, Anderson, & Sussman, 2012; Hakim & Ratner, 2004; Ludlow, Siren, & Zikira, 1997; Melnick, Conture, & Ohde, 2003; Weber-Fox, Spencer, Spruill, & Smith, 2004; Sasisekaran & de Nil, 2006; Sasisekaran, de Nil, Smyth, & Johnson, 2006; cf., Bakhtiar, Ali, & Sadegh, 2007; Hennessey, Nang, & Beilby, 2008; Vincent, Grela, & Gilbert, 2012). To date, the research related to the *metrical* aspect of phonological encoding has been restricted to descriptive research. Within these limited data, a positive correlation has been demonstrated between the metrical property of stress and stuttering during speech production (e.g., Brown, 1938; Hahn, 1942; Prins, Hubbard, & Krause, 1991; Natke, Grosser, Sandrieser, & Kalveram, 2002; Natke, Sandrieser, van Ark, Pietrowsky, & Kalveram, 2004; Wingate, 1984; Weiner, 1984).

Thus far, only two studies have investigated both segmental and metrical properties of stuttering concurrently (Burger & Wijnen, 1999; Wijnen & Boers, 1994). Wijnen and Boers reported adults who stutter exhibit less incremental encoding of initial segments of stressed syllables than typically fluent adults. In a larger follow-up study by Burger and Wijnen, this outcome was not replicated – adults who stutter demonstrated comparable segmental encoding to fluent adults in the presence and absence of initial stress. Despite these inconsistencies, taken together, preliminary data suggest that the speech fluency of persons who stutter may be uniquely compromised by the metrical (in addition to the segmental) aspect of phonological encoding.

Previous researchers developed a unique paradigm to assess the time course of phonological encoding in typically fluent adults. Employing a *silent phoneme monitoring task*, Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002) established that phonological encoding assigns *segmental* properties of speech in a left-to-right, incremental manner. In addition, authors observed significant delays in segmental assignment at points in which *metrical* properties, either syllabic stress or assignment of syllable boundary, were required. Authors interpreted these delays in the phonological time course to reflect the additional processing time required to assign metrical properties of speech. Schiller (2005) expanded this interpretation by manipulating syllabic stress in bisyllabic words. Results indicated in the absence of initial stress, significant differences were present only at the syllable boundary, suggesting that the “first encountered” metrical property delays encoding of the remainder of the speech plan.

If adults who stutter do in fact have difficulty with the metrical aspect of phonological encoding, then it seems reasonable to assume that the stress loci may be significantly more disruptive to the time course of phonological encoding than what has been reported for adults who do not stutter. More specifically, based on silent phoneme monitoring data reported for typically fluent adults (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002; Schiller; 2005), phonological planning in adults who stutter may be uniquely compromised by assignment of metrical stress on the initial syllable and assignment of other metrical properties, such as syllable boundary in the absence of initial stress. The present study will employ a silent phoneme monitoring task to examine the influence of select metrical properties of speech during phonological encoding in adults who do and do not stutter. These findings will inform our understanding of the role of phonological encoding beyond the demonstrated role of segmentation difficulties in individuals who stutter.

The following literature review will first discuss Levelt and colleagues’ (Levelt et al., 1999) model of speech production in typically fluent speakers with specific emphasis on phonological encoding. Following the review of this model, theoretical models of stuttering linked to phonological encoding will be summarized. Finally, a detailed account of literature investigating the contribution of segmental properties and metrical properties in adults who do and do not stutter will be provided which will lead into the specific aims of the current study.

Chapter 2: Literature Review

2.1 Levelt et al.'s (1999) Model of Speech Production

Levelt et al. (1999) proposed a comprehensive model of speech production which involves three inter-related levels of planning: the conceptualizer, the formulator, and the articulator. The conceptualizer determines the speaker's communicative intent and activates appropriate semantic and lexical representations required to convey the intended message. The output of the conceptualizer is a semantic-lexical concept, known as a lexeme, which requires morphological assignment. Lexemes serve as input for the formulator (e.g., [escort] + tense + aspect). The formulator is divided into two distinct sublevels. The first sublevel of the formulator is morphological encoding, which assigns appropriate morphological properties to the lexeme (e.g., [escort] + present tense, progressive aspect) to form the lemma. The lemma accesses the phonological word form to convey the morphological target (e.g., "escort*ing*"). The output of morphological encoding is the phonological word form, which serves as input to the second sublevel of the formulator, phonological encoding.

Levelt et al.'s (1999) model of phonological encoding is illustrated in Figure 1. After the word form (i.e., "escorting") is selected, the phonological system independently activates two distinct properties of speech simultaneously: *segmental* properties of the word form, and *metrical* properties of the word form. Segmental properties consist of a serial-ordered string of phonemes (i.e., [ə s k o r t ŋ]; segmental spell-out), which is activated simultaneously and without syllable position assignment. Metrical properties consist of number of syllables (indicated by __), syllable boundaries (indicated by /), and stress assignment (indicated by ˈ) (i.e., ___ / ___ˈ / ___ ; metrical spell-out). After activation both of the segmental and metrical properties, syllabic frames are made available incrementally, and individual phonemes are assigned to positions within syllabic frames in a left-to-right, incremental manner starting with the initial phoneme (i.e., /ə/) and ending with final phoneme (i.e., /ŋ/) to create three phonological syllables (i.e., [ə-skor'-tŋ]. Recombination of segmental properties with metrical properties is referred to as segment-to-frame association, or *syllabification*, the output of which is the *syllabified word form.* The syllabified word form then serves as input for phonetic encoding.

According to Levelt and colleagues (1989; 1999), phonological syllables are made available for phonetic encoding as soon as segmental assignment for the syllable is completed. Upon completion, each syllable triggers a corresponding articulatory 'score,' described as abstract phonetic parameters to be specified and modified during subsequent motor programming. For high frequency syllables, Levelt and Wheeldon (1994) propose an alternative route of phonetic encoding - the mental syllabary. The mental syllabary is described as a repository for high frequency, well-learned gestural scores that relieve the demands of rapid, online computation of phonetic code during connected speech. Levelt and colleagues also suggest that stressed and unstressed representations of the same phonetic string are stored separately within the mental syllabary, provided each occurs in the language with relatively high frequency. Gestural scores in the mental syllabary are triggered incrementally by segmental information made available from left-to-right during syllabification.

This information is then sent to the articulatory system to initiate speech production once the entire syllabified word form has been associated with an abstract phonetic code (Levelt & Wheeldon, 1994; however, see Cholin, Levelt, & Schiller, 2006;

Cholin, Dell, & Levelt, 2011, for alternative views of ‘scope of planning’). Because phonetic plans of individual syllables are assigned (or computed) incrementally, Levelt (1989) posits the phonetic code for syllables are stored within an “articulatory buffer” until articulation is initiated.

An important feature of Levelt and colleagues (1999) model of speech production is the internal speech monitor. As noted by Hartsuiker, Bastiaanse, Postma, and Wijnen (2005, p. 8), the precise nature of the information monitored within Levelt’s model has evolved over time. Levelt (1989) initially proposed the internal speech monitor identified phonetic code within the articulatory buffer. However, subsequent research suggested the internal monitor was instead sensitive to phonological code during syllabification (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002). This distinction should be made, as subvocal rehearsal of words in short-term memory, often referred to as “inner speech,” is thought to occur within the articulatory buffer and is presumed to be comprised of phonetic or articulatory properties of speech, but does not necessarily represent higher-level phonological code. Evidence to support this distinction is provided by comparable performance in rhyme-judgment and homophone identification tasks in the presence of articulatory suppression or concurrent retention of verbal items, such as digit or letter strings (Baddeley, Thomson, & Buchanan, 1975; Besner, Davis, & Daniels, 1981; Wheeldon & Levelt, 1995).

As noted by Wheeldon, Meyer, and Smith (2006), the incremental nature of Levelt et al.’s (1999) model serves as a particularly attractive model to describe typically fluent speech production. That is, phonological encoding provides the articulatory system rapid access to formulated speech code just prior to speech production (i.e., at minimum a stressed syllable, at maximum a single lexical word combined with an unstressed morpheme). The Levelt et al. model also accounts for context-dependent variability of production during connected speech by online computation of (a) stress assignment, and (b) syllable boundary assignment, during the syllabification stage. Fluent speech production is contingent on the timely, incremental re-assembly of phonological and metrical information prior to production. Since its inception, Levelt et al.'s model has served as the basis of several models of disfluent speech production (Postma & Kolk, 1993; Vasic & Wijnen, 2005), an adjunct framework for production-based accounts of stuttering (Packman, Code, Onslow, 2007), as well as multifactorial models of stuttering (Conture et al., 2006; see Figure 2). Given the focus of the present study, the following will detail theoretical models of stuttering that have been influenced by Levelt et al.'s model with particular emphasis on metrical properties of speech production.

2.2 THEORETICAL MODELS OF STUTTERING

2.2.1 EXPLAN model

Howell's EXPLAN model (EX: execution, PLAN: planning, 2011) proposes a temporal dyssynchrony between levels of speech production and speech execution as the mechanism by which stuttering manifests. The EXPLAN model is most appropriately described in the context of connected speech. Prior to execution, a unit of speech planning (size of unit not specified within the model, see Howell & Dworzynski, 2005) is processed and sent to the articulatory system. As this unit is being executed, the upcoming speech unit is planned simultaneously. If the plan for the proceeding speech unit is delayed during formulation, execution is not possible until sufficient time has been allowed for computation. During these moments when the plan is not computed in a timeframe commensurate with execution, non-stuttering speakers “stall” by inserting a pause or interjection. Adults who stutter, on the other hand, opt to “advance” motoric movements without a fully formulated speech plan, resulting in overt repetitions or prolongations of a partial speech plan.

According to Howell and Dworzynski (2005), content words of sufficient phonetic complexity trigger moments of disfluency due to co-occurrence with low word frequency, high phonetic complexity, position in relation to function words, and increased likelihood of carrying linguistic stress (Dworzynski & Howell, 2004; Howell, Au-Yeung, Yaruss, & Eldridge, 2006). The contribution of phonetic complexity as a significant contributor to stuttered speech has been discounted (e.g., Byrd, Coalson, Yang, & Moriarty, 2013; Coalson, Byrd, & Davis, 2010; Logan & Conture, 1997), but the notion that stuttering occurs due to a temporal mismatch between speech planning and speech execution remains plausible. Thus, further investigation into specific factors that influence the speed of planning and execution is warranted. Studies by Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002) suggest a combination of both segmental and metrical properties, rather than segmental properties alone, serve as more relevant factors to disrupt the time course of speech planning relative to execution.

2.2.2 Fault-line theory

Wingate’s (1988) fault-line theory describes a stuttered event as a breakdown between the initial phoneme and stress-bearing vowel nucleus within the initial syllable of a word. This breakdown is proposed to occur due to either a failure or a delay in the ability to retrieve the initial stress-bearing vowel. Difficulty ‘merging’ the initial consonant+vowel (CV) prior to articulation leads to a subsequent inability for the motoric system to advance, resulting in motoric 'tonus' events (i.e., prolonging or holding of muscular posture) and/or 'clonus' events (i.e., repetitive movements of speech musculature).

Evidence to support the proposed fault-line as the point of breakdown is drawn from (a) the observation that stuttering typically occurs on stressed words, (b) poorer performance by adults who stutter on meta-linguistic tasks such as backward speech, and "phonetic anagrams" (Wingate, 1988: pp.208-225), and (c) prior speech error data and theory by Martin (1972) and Shattuck-Hufnagel (1987) that suggest suprasegmental (i.e., stress) information has 'prior entry' during the language formulation process (Wingate, 1988: p. 248). That is, while stress-assignment/vowel errors are particularly rare, phonetic errors are most common during stressed syllables. Increased errors of initial phonemes in stressed syllables are thought to reflect a 'dynamic contrast' in processing load between the initial consonant and vowel.

Prosodic and phonological levels of processing are thought to be relatively distinct within this model, and the phenomenon of stuttering is further described as a lack of synchrony during word assembly which occurs prior to the level of motoric execution (Wingate, 1988: p. 267). The fault-line hypothesis addresses disruptions that may occur during segmental retrieval (i.e., initial CV) and retrieval of one metrical property (i.e., initial syllabic stress).

Wingate's (1988) theory has motivated two empirical studies which investigated the interaction between metrical stress and segmental encoding (e.g., Burger & Wijnen, 1999; Wijnen & Boers, 1994). Unfortunately, findings between these studies did not converge. Further, due to its restricted locus of breakdown, the proposed fault-line within this model accounts for only two stuttering-like disfluencies: sound repetitions and prolongations. Application of the model to the overt manifestations of stuttering is limited and would benefit from inclusion of metrical properties other than syllabic stress, such as assignment of the syllable boundary.

2.2.3 Vmodel

In contrast to psycholinguistic theories of stuttering, the Vmodel theory of stuttering (Packman et al., 2007) was derived from clinical data which assessed production-based changes during stuttered speech and fluency-enhancing techniques. In their Vmodel, stuttering is viewed as a result of underlying difficulties initiating well-learned, sequential motor programs, such as the speech syllable. Across fluency-enhancing techniques, the recurring factor during fluent speech of individuals who stutter was the reduction of variability in vowel durations (i.e., a more restricted range of long and short vowel durations during connected speech). Packman and colleagues assume this phonetic factor was the common thread that explained similar outcomes (i.e., enhanced fluency) in seemingly disparate tasks. They argue that reduced variation in vowel duration may be due to reduced variability of syllabic stress, a factor known to impact vowel duration (e.g., Crystal & House, 1988), during speech production.

The variability of syllabic stress during connected speech, in the context of less stable motor production abilities, delays access selection of the appropriate syllable gesture within the mental syllabary. Thus, linguistic stress is viewed as a trigger, rather than a cause, of stuttered speech. Authors concede that other equally stressful factors may produce similar results, but suggest that the combination of stress variation and underlying instabilities in the motor system is sufficient to induce a moment of stuttering.

In contrast to Wingate (1988) and Howell (2011), Packman et al. (2007)'s theory is based on the work of Levelt and colleagues (Levelt & Wheeldon, 1995) that suggests adult speakers access a 'mental syllabary', a repository of high-frequency syllable gestures, during production of connected speech. Levelt and colleagues posit that stressed and unstressed syllabic gestures are stored independently within the mental syllabary. Perhaps of greater importance to the present study, these high-frequency gestures are activated by the output from the phonological encoding process. Iin theory, both segmental and metrical factors contribute to the accurate selection of gestural scores prior to speech. Thus, the effects observed in studies that support the Vmodel may also reflect the impact of metrical factors at the level of phonological encoding.

2.2.4 Holistic encoding theory

Byrd et al. (2007) provides an alternative account of atypical phonological encoding in children who stutter. As described by Brooks and MacWhinney (2000), early speech-language development in fluent children is characterized by a shift from 'holistic' organization of word forms to 'incremental' organization of word forms. During the holistic organization stage, children learn new lexical items as global word forms with limited specificity of the segmental content. As communicative demands and vocabulary size increase, greater specification of segmental properties is required to quickly and efficiently differentiate between words of similar phonological properties. Re-organization of the mental lexicon by segmental information, rather than global lexical entries, enables faster retrieval of target word forms prior to production, and provides the segmental information necessary for segmental spell-out during phonological encoding.

Data from Byrd et al. (2007) suggest that children who stutter shift from holistic to incremental processing later in development than typically fluent children. In their explicit priming study, three-year-old children responded more quickly during a picture-naming task to auditory vowel+coda (-VC) primes than initial consonant primes (i.e., C-). At five-years of age, children who stutter continued to respond faster when provided (-VC) primes, while fluent peers responded faster with C- primes. Results were taken to suggest that children who stutter store, retrieve, and process speech using less efficient, global lexical representations. Holistic encoding has not been directly examined in adults who stutter, but difficulties observed during recall and repetition of nonword stimuli at later ages (e.g., Byrd, Vallely, Anderson, & Sussman, 2012; Hakim & Ratner, 2004; Ludlow et al., 1997) provide indirect evidence that novel lexical input is processed and stored inefficiently, similar to the unfamiliar stimuli learned at younger ages.

Although the holistic processing model provides detailed account for the nature of segmental encoding difficulties in children who stutter, the model is compromised by the exclusion of metrical properties of speech known to have equal influence on the phonological encoding process. Inclusion of both segmental and metrical properties within the model would provide greater specificity to the relationship between phonological encoding and moments of stuttered speech.

In sum, these theories of stuttering emphasize segmental properties, and two consider a single metrical properties of speech (i.e., stress) but do not isolate the unique contribution of each to stuttered speech. In addition, none of the theoretical models proposed stuttering or the efficiency of phonological encoding may be influenced by the assignment of syllable boundaries. According to Levelt et al. (1999), both segmental and both metrical properties (i.e., stress and syllable boundary assignment) are inherent to the phonological encoding process. Theories that posit phonological encoding as the potential locus of breakdown in individuals who stutter would benefit from consideration of all relevant factors, as each have the potential to perturb the timely encoding of speech plans. In the following section, literature that highlights the relationship and unique contribution of both segmental and metrical properties during segment-to-frame association will be reviewed.

2.3 Phonological encoding in fluent adults

Efficient assembly of the phonological code requires the incremental integration of both segmental and metrical aspects of speech production in a 'left-to-right' fashion. A fundamental component of Levelt et al.'s (1999) model of speech production is the ability to monitor internal phonological code generated during syllabification. The primary purpose of the self-monitoring system is to allow speakers to alter their intended message and/or identify errors prior to overt production. As noted by Levelt et al. (1999), the self-monitoring system can also be examined via experimental tasks. *Silent phoneme monitoring* is an experimental task that can be used to facilitate the examination of the time course of syllabification. This task is an adaptation of the external phoneme monitoring task used in speech perception studies (see Connine & Titone, 1996). During silent phoneme monitoring the participant identifies via non-verbal response (e.g., button-press) the presence or absence of a target phoneme within a target word.

Using a silent phoneme monitoring task, Wheeldon and Levelt (1995) presented adult participants (Dutch-English bilinguals) a word in English and instructed each to respond as quickly as possible, via button press, whether a specified sound was present in the Dutch translation (see Figure 3). All silently generated words were bisyllabic $C_1VC_2C_3VC_4$(C) stimuli, with either initial or non-initial stress. Results indicated that each consonant was identified faster than the following consonant (i.e., C1 < C2 < C3 < C4), suggesting that segmental information was made available during segment-to-frame association in an incremental, left-to-right manner. Significant differences in latencies occurred between C1 and C2, and C2 and C3. Authors interpreted these significant differences to represent the additional time required to assign metrical aspects of speech: initial stress (i.e., C1-C2: 55 ms) or syllable boundary (i.e., C2-C3: 56 ms) in words with non-initial stress.

In a subsequent study, Wheeldon and Morgan (2002) employed a silent phoneme monitoring task with typically fluent English-speaking adults. Participants first completed paired-word association training (i.e., prompt word: *frog*, target word: *tadpole*). Similar to Wheeldon and Levelt (1995), all target words were CVCCVC and stress assignment occurred on either the first or second syllable. Prompt words were then presented auditorally and participants were asked to monitor the target word for the presence of a target phoneme. Initial results indicated a replication of serial, left-to-right pattern of monitoring latencies observed in Wheeldon and Levelt (1995), again with significant differences between C1-C2 (109 ms) and C2-C3 (63 ms). See Figure 3 for graphs of silent phoneme monitoring in each study.

Jansma and Schiller (2004) provide further support for the additional time required during assignment of the metrical syllable boundary through the use of a go/no-go silent phoneme monitoring task of CVCVC bisysllabic stimuli. Across all trials, Dutch-speaking participants were told to monitor for the third serial phoneme. In one half of the stimuli, the third phoneme occupied the coda of the first syllable (i.e., /kan.sɛl; target sound underlined), and in the remaining half, the same phoneme occupied the onset of the second syllable (i.e., ka.no; target sound underlined). During the first block, participants were instructed to press a button if the pre-specified serial phoneme belonged to the first syllable, and withhold button-press if it did not. During the second block, participants were instructed to press a button if the pre-specified phoneme belonged to the second syllable.

Data indicated that phonemes that occupied the onset of the second syllable were monitored significantly later (i.e., 39 ms) than when the same phoneme occupied the offset of the first syllable. This significant difference was interpreted to reflect the additional time required to assign the syllable boundary during internal generation of speech, an interpretation also provided by Wheeldon and Levelt (1995) to explain the significant C2-C3 difference observed in their study. Significant C2-C3 differences were also observed by Wheeldon and Morgan (2002). However, upon subsequent removal of medial clusters with 'clear' syllable boundaries (i.e., illegal in both onset and coda position according to phonotactic constraints of English), C2-C3 differences diminished in magnitude.

Across studies (Jansma & Schiller, 2004; Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002), data revealed that phonemes were assembled and monitored at increasingly longer latencies (i.e., C1< C2 < C3 < C4). Findings suggest that segmental information is assigned in an incremental, left to right fashion. In addition, significant C1-C2 and C2-C3 latency differences were observed. Of note, all studies included stimuli sets composed of bisyllabic words with both initial and non-initial stress. Thus, significant latency differences were attributed to metrical properties due to co-occurrence within the phonological code. Further, phonological encoding occurs in a left-to-right incremental manner and thus prolonged latencies on the initial syllable potentially masked the magnitude of disruption at the syllable boundary.

To isolate the influence of metrical stress and syllable boundary assignment in phonological encoding, Schiller (2005) manipulated stress assignment of bisyllabic CVCCVC words during a silent phoneme monitoring task. As depicted in Figure 4, findings indicated that when internally generated words held initial stress, a significant latency difference was found between C1 and C2, with no appreciable difference between C2, C3, and C4. In contrast, words with non-initial stress exhibited no discernible difference in monitoring latencies between C1 and C2. Rather, latencies between C2 and C3 exhibited a significant latency difference, with C3 taking longer to monitor than C2. Schiller interpreted these data in the context of rightward segmental monitoring data found in both studies by Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002). That is, if speakers assemble and monitor phonological speech code from left-to-right, the first encountered metrical property requires additional time to compute, be it initial stress (i.e., C1-C2) or in the absence of initial stress, the first syllable boundary (i.e., C2-C3).

Schiller (2005) further explained that the lack of differences beyond the first-encountered metrical property could be explained within the context of Levelt et al.'s (1999) model of phonological encoding. In other words, during the time required to formulate the first metrical property, all subsequent segmental and metrical properties continue to be made available, and become immediately available after the initial metrical property has been completed (i.e., the "plateau effect").

Taken together, data from these silent phoneme monitoring tasks support the incremental encoding of segmental properties of speech during the phonological encoding process, with phonemes assigned to metrical frames individually and with progressively longer latencies. In addition, and in accordance with the model proposed by Levelt et al. (1999), metrical properties such as stress and syllable boundary assignment exert considerable influence on the time course of phonological encoding, in that the first-encountered metrical property from left-to-right requires additional time to compute.

In sum, both segmental and metrical properties have the potential to alter or delay the efficient phonological encoding necessary to maintain fluent speech production in non-stuttering adults. Using the paradigm put forth by Schiller (2005), the unique influence of individual metrical factors can be isolated to further specify the contribution of metrical factors, as well as segmental factors, to slowed phonological encoding in adults who stutter compared to typically fluent adults.

2.4 PHONOLOGICAL ENCODING IN ADULTS WHO STUTTER

Ample empirical data support differences in phonological encoding in adults who stutter relative to segmental properties of speech. To date, less attention has been paid to experimental investigation of the metrical properties required for syllabification: assignment of stress and syllable boundaries. Further, no study has investigated segmental properties and both metrical properties (i.e., assignment of stress and syllable boundary) simultaneously. According to Levelt et al. (1999) and subsequent research (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002; Schiller, 2005), both segmental and metrical properties are required during the phonological encoding process. Thus, data describing the potential influence of phonological encoding on speech production in individuals who stutter is incomplete as to date it has been largely restricted to segmental properties.

2.4.1 Segmental properties

The co-occurrence of phonological disorders and children who stutter is disproportionately higher than non-stuttering children (e.g., Blood, Ridenour, Qualls, & Hammer, 2003; Wolk, Edwards, & Conture, 1993; cf. Nippold, 2001) and the most frequent concomitant disorder with developmental stuttering (e.g., Arndt & Healey, 2001). Investigations in children who stutter have yet to detect a reliable link between overt moments of stuttering on overt speech errors (e.g., Wolk, Blomgren, & Smith, 2000) or increased phonetic difficulty (e.g., Byrd et al., 2013; Coalson et al., 2010; Throneburg, Yairi, & Paden, 1994). However, experimental data in children who stutter reveal more reliable disruption at the level of speech planning rather than speech production.

Reaction time data from external priming paradigms provide consistent evidence that children who stutter exhibit atypical phonological encoding strategies compared to normally fluent peers (Arnold et al., 2006; Byrd et al., 2007). In these studies, a child participant hears a phonological prime that matches either the initial phoneme or the remaining phonemes of a target picture prior to naming the picture. Data reveal that children who stutter do not benefit from pre-activation of segmental information prior to naming at 5-years of age, while non-stuttering children respond faster under the same condition. Instead, children who stutter benefit more from primes comprised of the global syllable shape; these nucleus plus coda related primes are typically found beneficial only at younger ages in fluent peers prior to efficient re-organization of the speech production system. Findings suggest that incremental, left-to-right encoding during speech production is compromised due to lexical entries that contained less detailed segmental information.

Further evidence of less robust segmental knowledge in children who stutter is provided by the lack of interaction between stuttering and phonological properties of speech (i.e., Anderson, 2007; Anderson & Byrd, 2008). In these studies, interaction between disfluency-type and segmental properties of speech manifest in a predictable fashion. Sound repetitions and prolongations were reported to originate from difficulties differentiating the target word from other words due to underspecified segmental detail in lexical entries, whereas single-syllable repetitions were thought to reflect difficulties without the assistance of segmental composition. Further influence of weaker phonological systems in children who stutter is reflected by poor performance during nonword repetition tasks, in which segmental knowledge cannot benefit from long-term lexical or semantic knowledge (e.g., Anderson & Wagovich, 2010; Anderson et al., 2006; Hakim & Ratner, 2004; cf. Bakhtiar et al., 2007).

Evidence of compromised phonological abilities in adults who stutter remains more indirect. For example, external or implicit priming paradigms do not reveal marked differences in adults who do and do not stutter (e.g., Burger & Wijnen, 1999; Hennessey et al., 2008; Vincent et al., 2012; cf. Wijnen & Boers, 1994). Residual differences in phonological systems have been revealed during tasks involving maintenance of novel phonetic strings in working memory (e.g., Byrd et al., 2012; Huinck, van Lieshout, Peters, & Hulstijn, 2004; Ludlow et al., 1997). Phonological working memory has been found particularly vulnerable to concurrent tasks (e.g., Jones, Fox, Jacewicz, 2012) or increased cognitive demand (e.g., Bosshardt, 1990, 1993; Bajaj, 2007; Weber-Fox et al., 2004) relative to non-stuttering adults. Overall slowed encoding and less accurate performance in adults who stutter often emerge in tasks that eliminate the production of overt speech (e.g., Brocklehurst & Corley, 2011; Postma et al., 1990; Sasisekaran et al., 2006; Sasisekaran & de Nil, 2008). Findings from non-verbal tasks indicate that motoric insufficiencies are not the sole source of difficulty in adults who stutter.

2.4.2 Metrical properties

The proposed link between phonological encoding and stuttering would benefit from investigation of metrical properties. As previously noted, descriptive data support a reliable link between overt moments of stuttering and metrical stress (e.g., Brown, 1938; Hahn, 1942; Wingate, 1988), with the observation that stuttering occurs more often on stressed syllables than unstressed syllables[1]. For example, Prins, Hubbard, and Kraus (1991) found adults who stutter were more likely to stutter on stressed syllables than unstressed syllables during read passages, and that this distribution was present independent of utterance-initial position. Natke, Grosser, Sandrieser, and Kalveram (2002) found adults who stutter were more likely to stutter on stressed syllables at both the utterance initial syllable and subsequent syllable within an utterance. In an investigation of spontaneous speech samples of children who stutter, Natke, Sandrieser, van Ark, Pietrowsky, and Kalveram (2004) suggested that different types of stuttering

[1] For the purposes of the current study, a distinction must be made between word-based stress and syllabic stress, as the two are often confounded in previous works. For example, Klouda and Cooper (1988) found adults were more likely to stutter on the stressed (polysyllabic) word in a sentence. Contrastive stress was considered a property governed largely by speakers' communicative intent, while the latter is considered to be metrical properties inherent to the word itself and governed most by lemma selection (e.g., "PERmit" versus "perMIT") or context-based morphological factors (e.g., "COGnitive" versus "cogNItion").

occur somewhat predictably based on temporal relationship to syllabic stress. Descriptive data support the present hypothesis that metrical stress compromises the fluency of conversational speech of both children and adults who stutter.

Natke et al. (2002, 2004) provide specific predictions of stuttering type based on metrical stress assignment. Natke et al. (2002) analyzed syllabic stress, word position, and frequency of stuttering from 16 adults who stutter. Along with clear word initial effects, authors found stressed syllables more likely to be stuttered than unstressed syllables. In their follow-up study (2004), a similar analysis was applied to speech samples of 22 children who stutter and controlled for grammatical classification. Findings replicated the adult study, in that word-initial syllables provoked almost every instance of stuttering (98%), and stressed syllables were stuttered at significantly higher rates than unstressed syllables. Further, prolongations and part-word repetitions occurred more frequently on stressed syllables, while monosyllabic repetitions occurred on syllables just before stressed syllables (defined by authors as “intermediate stress”).

The location of metrical disruption described by Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002) and Schiller (2005) coincide with Natke et al.’s (2004) report of disfluency type in relation to stress. Metrical stress assignment on the vowel within the initial syllable would, in theory, delay access to subsequent segmental information (e.g., C2, C3, and C4). If individuals who stutter exhibit difficulty storing and retrieving metrical properties, as observed for segmental properties, the magnitude of delay when assigning initial metrical stress may become more pronounced. If speech production is initiated prior to completion, the articulatory system may attempt to produce speech with only a partial speech plan. In the case of initial stress assignment, the speech plan may consist of only the initial consonant and result in prolongation or repetition of the initial segment. In the case of non-initial stress, additional time required to assign the syllable boundary may result in a partial speech plan that consists of only the initial syllable and result in a monosyllabic word repetition. Both potential articulatory outcomes are consistent with those Natke et al.'s observed patterns of disfluency. Findings motivate further examination of temporal disruptions in phonological encoding in individuals who stutter during assignment of metrical properties.

2.4.3 Segmental and metrical properties

Beyond descriptive research, experimental research regarding the phonological encoding abilities of adults who stutter in the presence of stress remains limited to two studies. During an implicit naming paradigm using words with only initial-stress, Wijnen and Boers (1994) found speech onset latencies were faster for adults who stutter and were shorter when the target word shared initial consonant+vowel, but not the initial consonant in isolation, suggesting that adults who stutter have difficulty encoding the stress-bearing vowel of the initial syllable. In a subsequent study with a larger number of participants, Burger and Wijnen (1999) manipulated the stress assignment of bisyllabic stimuli. The between-group priming effect observed in Wijnen and Boers did not emerge, suggesting that phonological encoding did not differ appreciably between groups, nor did it interact with stress assignment. Although equivocal, the studies serve as preliminary data that support the potential interaction between metrical and segmental properties of speech. These studies are limited, however, in how metrical properties were defined. The influence of metrical assignment of syllable boundaries would not emerge in these studies, as regions of interest are restricted to initial segments within the first syllable.

As demonstrated by Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002), greater insight into the influence of both segmental and metrical properties during phonological encoding is provided by silent phoneme monitoring tasks of bisyllabic stimuli. Sasisekaran et al. (2006) compared the phoneme monitoring latencies of adults who do and do not stutter. In this study, participants heard the verbal target (e.g., "Please respond to the /sə/ sound in the following picture") and were then presented with one of 14 picture stimuli names in random order. All stimuli were bisyllabic CVCCVC, but unlike previous studies by Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002), only included words with initial syllabic stress.

Data from Sasisekaran et al. (2006) revealed two main findings. First, adults who stutter exhibited significantly slower latencies for all consonant positions (i.e., C1, C2, C3, and C4). Authors interpreted this group difference to support an overall slowness in phonological encoding in adults who stutter. Second, similar to Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002), both groups identified C1 significantly faster than C2, C3, and C4. However, unlike Wheeldon and colleagues, no significant difference was observed between consonants that flank the syllable boundary (i.e., C2 and C3; see Figure 5).

Lack of a significant difference at the syllable boundary assignment for typically fluent adults, and adults who stutter, may be explained by the results of Schiller (2005). Given that all CVCCVC stimuli within the study held initial stress, it is possible that the remaining segmental (i.e., C2, C3, and C4) and metrical properties (i.e., syllable boundary) continued to be made available during the assignment of stress on the first syllable. Thus, the observed “plateau” pattern may be due to uniform metrical stress across all stimuli.

Metrical stress was manipulated in a study by Sasisekaran and de Nil (2006). After a familiarization phase, adults who do and do not stutter completed a silent phoneme monitoring task which incorporated compound word (i.e., hotdog) and noun phrase (e.g., hot dog) variants of CVCCVC stimuli, with the latter carrying stress on the second syllable. Authors examined only C2 and C4 response latencies. Results again indicated that adults who stutter were significantly slower regardless of condition. Results also indicated that both groups, contrary to prediction, monitored C4 more slowly than C2 in compound words (i.e., initial stress) but there was no effect of consonant position in noun phrases (i.e., secondary stress). In addition, there was a non-significant trend for faster response latencies for noun phrases compared to compound words.

Authors discounted the possibility of limited differentiation between stimuli. Instead, they suggested unexpected differences may be due to strategic encoding specific to the linguistic nature of the unit of speech to be planned. Moreover, given the possible influence of linguistic factors, and the lack of data for C1 or C3, limited interpretation of the influence of metrical properties, such as syllabic stress or the influence of syllable boundaries, on phonological encoding can be made. However, the significant difference between C2 and C4 does not discount the potential influence of metrical syllable boundary assignment, regardless of lexical stress pattern.

Similar to past studies, recent silent phoneme monitoring data from nine children who stutter and nine typically fluent peers (10 to 14 years of age; Sasisekaran, Brady, & Stein, 2013) indicate participants who stutter exhibit mean response latencies that are slower than fluent peers. As in Sasisekaran et al. (2006), CVC(C)CVC stimuli were comprised of initial syllable stress. There was a significant main effect of consonant position, with increased mean latencies for each consonant relative to the preceding consonant for both talker groups. However, children who stutter were significantly slower than fluent peers when monitoring C3 and C4. Authors refer to the work of Jansma and Schiller (2004) and suggest this finding may reflect the additional time necessary to process the syllable boundary.

Although within group latency differences between consonants were not reported in Sasisekaran et al. (2013), data support an alternative account for phonological encoding in younger stuttering and non-stuttering participants. The apparent lack of between-group differences when monitoring C1 and C2 in words with initial stress, combined with the significant effect of position, suggests that C1-C2 differences were significant for both talker groups. These findings also support the notion that words with initial stress required greater processing time between C1 and C2. However, significantly longer latencies for children who stutter after the syllable boundary compared to children who do not stutter suggest that in typically fluent children, increased time required to process syllable boundary may be afforded by the presence of initial stress. In contrast, children who stutter require additional time to process the syllable boundary in addition to the temporal window already provided by initial stress. To fully investigate the role of syllable boundary assignment in the phonological encoding differences previously observed in children and adults who stutter, experimental manipulation of stress from initial to non-initial position is warranted.

2.5 CROSS-LINGUISTIC SEGMENTAL AND METRICAL ENCODING IN ADULTS WHO STUTTER

The influence of metrical properties is not restricted to stress-based languages (e.g., English, Dutch, German). Zhang and Xiao (2008) conducted a silent phoneme monitoring task in which Mandarin Chinese-speaking adults who do and do not stutter were instructed to monitor the segmental onset (i.e., shengmu), following vowel (i.e., yumu) and tone associated with the vowel in bisyllabic CVCV words. Results indicated that both talker groups monitored the onset phoneme of the first syllable faster than the onset of the second syllable. No significant difference or interaction was observed between groups, but a significant interaction was found when monitoring the subsequent vowel in each syllable. Adults who stutter monitored the vowel of the second syllable significantly more slowly than typically fluent adults. In addition, the stuttering participants monitored the tone associated with the vowel in both syllables significantly more slowly than fluent adults.

Authors interpreted these data to support the locus for "temporal desynchronization" between phonological planning and motoric execution. Authors also suggest difficulty accessing the initial consonant as the reason for temporal delay of the following vowel and tone. Thus, it can be argued that, across languages, adults who stutter show particular difficulty encoding any metrical property of speech, be it tone or stress, relative to fluent speakers.

Some support for metrical encoding as a source of potential variability between speakers comes from investigation of implicit priming of metrical properties in Mandarin Chinese by Zhang and Damien (2009), who found that typically fluent adults monitored target tones more slowly than segmental information when instructed to silently generate CV(C) stimuli. In addition, although peak N200 latencies were similar for segmental and metrical targets, the onset of N200 for metrical primes was approximately 200 ms slower than segmental. While supporting the independent storage and parallel retrieval of segmental and metrical information suggested in Levelt et al. (1999), authors provide preliminary data to suggest that metrical properties may not necessarily be initiated in tandem, and activation may in fact lag behind segmental activation while “arriving” at the same time for phonological encoding.

Given the potential, subtle dissociation between the time course of segmental and metrical retrieval, it stands to reason that efficient processing of each type of information can be compromised independently, or co-occurring compromise may exist. In the case of Zhang and Xiao (2008), it is possible that adults who stutter were particularly challenged by metrical processing, while segmental encoding remained largely intact. Further, it is also possible that segmental information potentially has a “head-start” in initial activation, while metrical information may exhibit an underlying delay in activation, and perhaps more easily disrupt the phonological time course if storage or retrieval of metrical information is somehow compromised. If metrical encoding systems are compromised due to unique language experiences, metrical information may not arrive simultaneously with segmental information.

A series of studies by Shimamori and colleagues (Matsumoto-Shimamori, Ito, Fukuda, & Fukuda, 2011; Shimamori & Ito, 2006; 2007; 2010) provides support that syllabic boundary assignment contributes uniquely to moments of stuttering. In these studies, researchers investigated the frequency of stuttering in Japanese children who stutter based on the syllable weight and transition from initial vowel to consonant following the initial syllable boundary. Heavy syllable weight was defined by authors as including two ‘moras’ (i.e., diphthongs, long vowels, nasal consonants, and geminate stops). Light syllable contained one mora (i.e., short vowel). During nonword reading tasks (2006) and nonword naming tasks (2007), greater stuttering was observed on words beginning with light moras than heavy moras. In heavy syllables (i.e., diphthongs, nasals, and geminates) vowels were followed by another intra-syllabic phoneme (e.g., CVV.C, CVC.C); in light vowels, the initial vowel was followed by a syllable boundary, then a phoneme (i.e., CV.C). Thus, the critical factor between light and heavy syllables was the inclusion of the syllable boundary between the upcoming, adjacent phoneme.

Further investigation by Matsumoto-Shimamori et al. (2010) supported Schiller's (2005) prediction that the first-encountered syllable boundary was the pivotal metrical property. As in their previous studies, authors reported greater stuttering on light syllables than heavy syllables in initial position. However, stuttering did not increase with additional syllable boundaries within two- to five-syllable nonwords. Taken together, these findings place a significant emphasis on the transition across the initial syllable boundary as a critical factor in childhood stuttering. Syllable boundaries that are encountered sooner to the initiation of speech (i.e., after a light CV.C syllable) are more likely to result in stuttered speech than later (i.e., after a heavy CVC. or CV_1V_2.).

In the Shimamori studies, greater stuttering observed on words with light initial syllables (i.e., CV with short vowel) suggests the importance of time required to compute the syllable boundary. The most common type of disfluency expected, based on the same rationale applied to Natke et al. (2004), would be the monosyllabic word repetition (i.e., onset + initial mora). This pattern was reported by Ujihira (2011), with repetition of the initial phoneme (i.e., k-k-k kat) occurring infrequently compared to its high-frequency of occurrence in English.

Data from Japanese and Mandarin Chinese speakers, for whom metrical properties are arguably more demanding and communicatively salient than in Germanic languages, further highlight the importance of metrical encoding and the possible phonological consequences of complex metrical encoding. In addition, metrical properties such as syllable boundary emerge as a relevant factor regardless of stress assignment. It can be argued that, similar to Schiller (2005), the initial time required to encode tone in the first syllable observed in Zhang and Xiao (2008) allowed the metrical property of syllable boundary assignment and second-syllable onset to become available. However, the additional tone encoding required for the second syllable (i.e., not present in typically Germanic bisyllabic words with initial stress) could not be compensated for by the increased encoding of the initial vowel.

In sum, metrical properties appear to retain significant influence on the time course of phonological encoding across languages. Further, given that stuttering is a universal phenomenon across cultures, these data lend cross-linguistic support for the present hypothesis that the metrical properties of phonological encoding may play a critical role in the difficulties persons who stutter have maintaining and/or establishing fluent speech.

2.6 Rationale

The relatively limited data collected to date suggest that stress and syllable boundary assignment may disrupt the time course of phonological encoding, and perhaps provoke greater moments of stuttering. Previous examinations of the effects of stress and syllable boundary assignment were confounded by the lack of control for stress loci across stimuli. Wheeldon and colleagues (Wheeldon & Levelt, 1995;

Wheeldon & Morgan, 2002) reported significant differences in monitoring latency between C1 and C2, and C2 and C3 consonants. Stimuli in these studies included bisyllabic words with both initial and non-initial stress.

In contrast to Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002), Sasisekaran et al. (2006) used bisyllabic stimuli with only initial stress. Similar to Schiller (2005), C1-C2 latency differences on the initial stressed syllable were significant, with C2 identified later than C1 phonemes. C1-C2 differences were more pronounced in adults who stutter, suggesting that assignment of initial stress required additional time.

Sasisekaran and colleagues (2006) did not analyze the presence of the observed C1-C2 difference but given the magnitude of difference (i.e., approximately 100 ms), it is reasonable to assume that C2 phonemes were significantly delayed in adults who stutter relative to initial phonemes. Descriptive data by Natke et al. (2004) suggest that intra-syllabic disfluencies (i.e., prolongations and sound repetitions) commonly occur on initial stressed syllables, a plausible outcome of delayed assignment of C2 phonemes. Thus, examination of within-group difference at C1-C2 positions during silent phoneme monitoring in adults who do and do not stutter is warranted.

To date, there has yet to be an examination of the potential influence of delayed phonological encoding due to assignment of syllable boundaries. Empirical data reported by Schiller (2005) suggest that processing time at the syllable boundary is more pronounced upon removal of initial syllabic stress. In specific, C3 latencies were significantly delayed relative to C2 phonemes just prior to the syllable boundary and without an intervening phoneme. If adults who stutter exhibit significantly delayed assignment of metrical properties, as observed in Sasisekaran et al. (2006), it is reasonable to assume that syllable boundary assignment is similarly affected. If this is the case, C2-C3 latency differences may be more pronounced in adults who stutter, relative to typically fluent adults, due to greater delay during assignment of phonemes following the syllable boundary (i.e., C3).

Descriptive findings of Natke et al. (2004) suggest that monosyllabic repetitions are common prior to stressed syllables, a potential articulatory outcome of delayed assignment of C3 phonemes. Thus, examination of C2-C3 phonemes in the absence of initial stress during silent phoneme monitoring in adults who do and do not stutter is also warranted. Isolation of metrical properties by manipulation of stress patterns, as observed in typically fluent adults in Schiller (2005), would inform the unique contribution, if any, of metrical properties on phonological encoding in adults who stutter.

2.7 SPECIFIC AIMS

In the current study, two specific research questions were examined in two separate experiments. In Experiment 1, we examined the influence of metrical stress on the segmental encoding of $C_1VC_2C_3VC_4$ nonwords with initial stress in adults who do and do not stutter using a nonword silent phoneme monitoring task (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002; Sasisekaran et al., 2006; Zhang & Xiao, 2008). In Experiment 2, we examined the influence of metrical syllable boundary assignment on the segmental encoding of $C_1VC_2C_3VC_4$ nonwords with syllable boundary as the first-encountered metrical property (Schiller, 2005), again using a nonword silent phoneme monitoring task.

Thus, the two experiments conducted within this study were designed to address the following research questions:

1) Does the metrical property of initial stress assignment contribute to slower phonological encoding in adults who stutter relative to typically fluent adults? Specifically, are C1-C2 differences longer in adults who stutter due to prolonged C2 latencies?
2) Does the metrical property of syllable boundary assignment, in the absence of initial stress, contribute to slower phonological encoding in adults who stutter relative to typically fluent adults? Specifically, are C2-C3 differences longer in adults who stutter due to prolonged C3 latencies?

Findings will inform the relative contribution of metrical properties to the time course of phonological encoding in adults who stutter. Findings will also provide greater specificity to fluency intervention strategies that incorporate phonological awareness in children who stutter, as well as fluency-enhancing techniques for adults who stutter.

Chapter 3: Nonword silent phoneme monitoring – Initial Stress

3.1 Methods

3.1.1 Participants

Experiment 1 included 22 adults (AWS = 11, age range: 18 to 41 years; AWNS = 11, age range: 18 to 26 years) from central Texas and surrounding areas with monolingual or native-like proficiency in Standard American English. Each talker group was balanced for gender (7 males, 4 females in each group) and as closely as possible for age (+/- 15 years or less). Participants were naïve to the specific variables of the study. This study was approved by the Institutional Review Board at the University of Texas at Austin. Written consent was obtained from each participant prior to participation and each participant was reimbursed.

3.1.1.1 Inclusionary criteria

To qualify for inclusion, participants met the following criteria: (a) 18 years of age or older, (b) no history of cognitive, developmental, or neurological disturbances, (c) no reported current use of antipsychotic medications, and (d) be monolingual English speakers or demonstrate native-like proficiency in Standard American English. A total of 37 participants (16 AWS, 21 AWNS) were initially recruited for the study and inclusion was determined upon completion of the following factors.

3.1.1.2 Demographic and background data

To establish demographic, academic, and medical profile, all participants completed a self-report questionnaire providing (a) age, gender, race and/or ethnicity, primary language(s) spoken, and socio-economic status (SES) as determined by level of education and job status, and (b) prior or current medical, reading and/or learning difficulties as well as current medications. Of the initial 37 participants, six participants (3 AWS, 3 AWNS) were not included due to current use of antipsychotic medications (i.e., Adderall, Strattera).

In addition to self-reported handedness, participants completed a formal handedness screening (Edinburgh Inventory: Oldfield, 1971). A summary of current and prior speech or language treatment history for individuals who stutter was also obtained. Of the initial participants, two AWNS were not included due to noted phonological deficits by examiner, a licensed speech-language pathologist.

3.1.1.3 Language background

For speakers with knowledge of more than one language, native-like English proficiency was determined by (a) qualitative assessment by licensed speech-language pathologist of proficiency and degree of accent during speech samples, and (b) self-rated proficiency and degree of accent in English. Self-reported data were based on the Language History Questionnaire (LHQ: Li, Sepanski, & Zhao, 2006), which includes a 7-point scale of proficiency in speaking, comprehension, reading, and writing scores in English (i.e., 7 = “native-like”) and a 6-point scale of accent when speaking English (i.e., 1 = “no accent”). Participants were excluded if average proficiency scores across modalities in English were below 6 (i.e., “very good”) or degree of accent greater than 1 (i.e., “no accent”). Of the 37 initially recruited, one AWNS recruit was excluded due to self-reported non-native like proficiency in English (i.e., score < 6).

3.1.2 Exclusionary Criteria

Of the remaining 28 participants (13 AWS, 15 AWNS) who met the inclusion criteria, participants were excluded from the study if (a) hearing screening, vision screening, or phoneme exposure probe were not passed, (b) baseline manual reaction time were 2 SDs above or below the mean relative to the participants' talker group (i.e., AWS or AWNS). Remaining participant groups were gender-balanced according to the gender ratio observed in the stuttering population.

3.1.2.1 Hearing and vision

Participants were required to complete two hearing assessments prior to experimental testing. First, a bilateral pure tone hearing screening was conducted at 20 dbHL for 1000, 2000, 4000, and 6000 Hz (American Speech-Language-Hearing Association, 1997). Testing at 6000 Hz was included given the typical frequency range of fricatives when presented in isolation, as used in the current study. Second, to assess the functional auditory discrimination abilities required for the experimental task, each participant completed a phoneme identification probe after a phoneme exposure task. During the exposure task, participants heard each target phoneme and saw the corresponding orthographic letter four times in random order. After exposure, participants were asked to identify the letter associated with each phoneme when presented auditorally in randomized order without visual cue. Participants were excluded if they could not identify all phonemes with 100% accuracy (i.e., 4 out of 4 presentations). Of the 28 participants, four participants (2 AWS, 2 AWNS) did not pass hearing assessments.

As with hearing, participants were asked to describe their present vision abilities. Participants also completed a near-vision acuity vision screening with a score of 20/30 or better, considered sufficient to read newsprint at 40 cm (i.e., “range of normal vision,” ICD-9-CM: US Department of Health and Human Services, 1996). Participants were excluded if any of hearing or vision assessments were not passed. None of the 24 participants were excluded based on vision abilities.

3.1.2.2 Baseline manual reaction time

Similar to Sasisekaran et al. (2006), participants responded manually to a visual icon presented in one of four corners of the computer monitor at randomized intervals: 500, 1000, 1500, and 2000 ms. Participants were asked to respond to the presence of the icon as quickly as possible by pressing a single button using their dominant hand. Reaction times based on speed of button-press were measured and averaged across position, trials and intervals. Participants were excluded if manual reaction time exceeded 2 SD (*z*-scores) from the mean of their talker group. None of the 27 participants were excluded based on baseline manual reaction time.

The remaining 24 participants (11 AWS, 13 AWNS) were balanced for gender and age with age-matching occurring to the closest degree possible based on the distribution within the AWS group. Male AWNS of the most frequently occurring age (i.e., 19-years of age) were randomized and the first two were selected for removal. The final participant pool resulted in 22 participants (11 AWS, 11 AWNS; 7 males and 4 females in each group).

3.1.3 Talker group classification

The primary criteria used to confirm AWS status of a participant was (a) self-identification as an individual who stutters with onset reported prior to the age of seven, and (b) prior diagnosis of stuttering by a licensed speech-language pathologist. If the participant had not received a formal diagnosis of stuttering, AWS status was further confirmed by the primary investigator, a licensed speech-language pathologist.

3.1.3.1 Speech samples

Prior to experimental testing, all participants provided two speech samples: a conversational sample (of no less than 300 words in length) and reading sample (337 words in length). Conversational and reading samples were counterbalanced for order within and across participant groups.

A participant was considered AWS if he or she exhibited an overall score of 2 or higher on a 9-point severity scale (1 = no stuttering, 5 = moderate stuttering, 9 = extremely severe stuttering: O'Brian, Packman, Onslow, & O'Brian, 2004) on *either* the conversational speech sample or reading passage. This scale has been found a valid measure of stuttering severity by O'Brian et al. (2004) and effectively used in three recent studies (Byrd, Logan, & Gillam, 2012; Byrd, Vallely, Anderson & Sussman, 2013; Logan, Byrd, Mazzocchi, & Gillam, 2011).

Of the 11 participants who self-identified as an AWS, six had received a formal diagnosis of stuttering from a certified speech-language pathologist. The remaining five participants who had not received a formal diagnosis of stuttering, but self-identified as a person who stutters, exhibited a score of 2 or higher during either conversational or reading sample. The remaining 11 participants that did not meet these criteria (i.e., no previous diagnosis of stuttering, did not self-identify as a person who stutters, and did not score above 1 on the stuttering severity scale) were considered AWNS. See Tables 1 and 2 for individual fluency performance of AWNS and AWS participants.

3.1.3.2 Reliability

Inter-rater reliability of stuttering severity for speech as samples was determined by the author and an undergraduate research assistant trained in disfluency count analysis. Six of the 22 participants (27%; 3 AWNS, 3 AWS) were selected at random and two-way mixed model inter-class coefficient was conducted to assess reliability of stuttering severity within and across speech samples. Intra-class coefficients were conducted by the author approximately one month after initial scoring.

For conversational samples, severity ratings for AWNS participants were in 100% agreement for all three participants, all of which received a score of 1 (i.e., "*no stuttering*"). For AWS, inter-rater reliability for conversational samples was within one point for 100% of the participants (*n* = 3), with all participants receiving a score of 2 or higher (range: 2 = "*very mild stuttering*" to 7 = "*moderate to severe stuttering*").   Inter-class coefficient was.95 between raters. Intra-rater reliability assessment found exact scores for 66% of the participants (*n* = 2), and within one point for the remaining participant. Intra-class correlation value of .96 for conversational samples

For reading samples, severity ratings for AWNS participants were in 100% agreement for all three participants, all of which received a score of 1 (i.e., "no stuttering"). For AWS inter-rater reliability for reading passage was exact for 33% of the participants (*n* = 1), and within one point for the remaining 67% (*n* = 2), with participants receiving a score of 2 or higher (range: 2 = "*very mild stuttering*" to 8 = "*severe* *stuttering*"). Inter-class coefficient was.97 between raters. Intra-class reliability assessment found exact scores for 66% of the participants, and within one point of the remaining participant. Intra-class correlation was .97 for reading samples. For both speech samples from AWS participants (n = 6 samples) inter-class coefficient was .95, with .97 intra-rater correlation coefficient (severity range: 2 = "*very mild stuttering*" to 8 = "*severe stuttering*").

3.1.4 Phonological processing subtests

To assess the phonological abilities of each talker group, participants completed nine tasks selected to assess phonological segmentation and working memory skills. Three subtests from the Comprehensive Test of Phonological Processing (CTOPP; Wagner Torgesen, & Rashotte, 1999) were administered to each participant to assess segmentation and working memory abilities, including nonword repetition (Subtest V) and onset identification and generation in words and nonwords (Subtest XI and XII, respectively). To measure onset generation abilities in real words and nonwords, the latter two subtests were modified and participants were also asked to "Provide another word that starts with the same first sound" after each test item.

Rhyme identification and generation abilities were assessed using two criterion-referenced tasks, similar to those used in Sasisekaran and Byrd (2013). Each task was 15 items in length (10 real words, 5 nonwords). During the identification task, participants responded 'yes' or 'no' to indicate whether two auditorally-presented items rhymed. During the generation task, the participant provided a word that rhymed with an auditorally-presented item.

Finally, similar to Sasisekaran and Byrd (2013), participants completed a forward and backward digit span task to further assess working memory abilities using the Wechsler Adult Intelligence Survey – Fourth Edition (WAIS-IV: Wechsler, 2008) Optional Digit Span Subtests. A maximum of 16 items were included for each subtest, ranging from two to eight numbers in length and two trials per number-length. Subtests were discontinued after both trials for a particular item were incorrectly recalled.

3.1.5 Tone series monitoring task

Similar to previous silent phoneme monitoring studies (Sasisekaran et al., 2006; Zhang & Xiao, 2008), all participants completed a non-linguistic auditory monitoring task. The purpose of this task is twofold. First, according to Wheeldon and Levelt (1995), internal and external phoneme monitoring considered to be governed by the same monitoring system. Thus, assessing the speed and accuracy of external monitoring abilities provides a reasonable estimation of the internal monitoring abilities. Second, baseline data monitoring non-linguistic stimuli will better inform to what degree observed variations in speed and accuracy are due to the phonological encoding process, rather than general abilities of the individuals' motoring system.

Each participant heard 96 auditory stimuli consisting of a four-tone sequence. Half of the stimuli (n = 48) was composed of four identical 500 Hz tones presented for 550 ms, each tone 100 ms in duration with 50 ms ISI between tones. The remaining half (n = 48) included three 500 kHz tones and one 1000 kHz tone occurring as either the first, second, third, or fourth tone within the series. After brief familiarization with the low (500 Hz) and high (1000 Hz) tones, participants were instructed to "Press 'Yes' button if they heard the high tone anywhere in the series," and to "Press the "No" button if you do not hear the high tone." Sequence of presentation was as follows: orienting cross in center of screen (500 ms), simultaneous auditory presentation of tone series accompanied with visual cue in one of four corners of the computer monitor. The program advanced after participant pressed Yes or No button, or 3000 ms had elapsed. All 96 stimuli were presented in randomized order, and resulted in a total of 48 "No" response and 48 "Yes" responses, 12 per auditory position, presented three times in each of the four corners of the screen.

3.2 Experimental design

As was the case in the previously reviewed phoneme monitoring studies, the purpose of the present study is to assess phonological encoding. However, because previous studies have used real word stimuli, attributing previous findings exclusively to the phonological encoding processes remains speculative. Multiple factors inherent to real word stimuli are known to influence speed and accuracy of participant response, including word frequency (e.g., Newman & German, 2005; Vitevitch & Sommers, 2003), phonological properties (e.g., Luce & Pisoni, 1998), semantic representation, and possible syllabification from the canonical form (e.g., Jansma & Schiller, 2004; Treiman, Gross, & Cwikiel-Glavin, 1992). In contrast to real words, nonwords allow greater isolation of the phonological encoding process, minimize semantic influence, and provide an opportunity to construct stimuli balanced for factors known to influence phoneme monitoring performance.

3.2.1 Nonword stimuli

The purpose of Experiment 1 was to investigate the metrical property of initial stress. As such, all 12 nonwords stimuli carried stress on the initial syllable of the bisyllabic nonword.

As shown in Table 3, 10 additional factors were considered during construction of nonword stimuli when balancing stimuli for lexical, phonological, and phonetic properties of speech. Word shape held constant CVCCVC for all nonword stimuli. As noted by Gathercole, Willis, Emslie, and Baddeley (1991), nonwords that resemble real words in consonant-vowel frame are identified more quickly. Word-likeness was determined by presenting each nonword auditorally to 10 adult listeners who did not participate in the study. These 10 adult listeners rated each nonword using a 5-point Likert scale described in Gathercole (1995): 1 = *very unlike a real word*, 5 = *very like a real word*. Mean word-likeness for all words were rated between *unlike a real word* and *neutral* when produced with both initial and non-initial stress (2.62 and 2.75, respectively).

Differences in neighborhood density and frequency, as well as phonotactic probability, have been reported to affect naming responses in fluent adults (Vitevitch, Luce, Pisoni, & Auer, 1999) as well as disfluencies in adults who stutter (Anderson, 2007; Anderson & Byrd, 2008). Average segmental and biphone phonotactic probability values for each nonword were obtained using an online calculator (Vitevitch & Luce, 2004). Phonotactic properties were low (segmental: .180 and biphone = .006) and no outlier within the nonword stimuli were present (*z*-score range: -1.43 to 1.24).

Neighborhood property values were obtained from the Hoosier Mental Lexicon (HML) adult database (see Luce, Pisoni, & Goldfinger, 1990; Luce & Pisoni, 1998; available at http://128.252.27.56/neighborhood/Home.asp). Values for neighborhood density and frequency were 0 for all words, indicating that none of the words were similar to a real word by one phoneme.

Phonetic complexity has been reported by some to influence speech planning in adults who stutter (Howell & Dworzynski, 2005; Howell et al., 2006; cf. Coalson, et al., 2012). Thus, this measure was calculated for each nonword using the Word Complexity Measure (WCM: Stoel-Gammon, 2010: mean complexity 6.17 across stimuli).

Levelt and colleagues report faster response times for words that contain high syllable frequency compared to low (Levelt & Wheeldon, 1994; Cholin et al., 2011). Syllable frequency for first and second syllable of each word was calculated using the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). Initial and final syllable frequencies ranged from 0 to 7 per million words, and the difference between syllables within each set was low and non-significant.

Finally, two properties of particular importance to phoneme monitoring tasks, uniqueness point and syllable boundary clarity, have been balanced across nonword stimuli. The uniqueness point is the phoneme, starting from onset, in which a word diverges from all other words (Ozdemir, Roelofs, & Levelt, 2006). According to Ozdemir et al., phonemes located after the uniqueness point are identified significantly faster, and the further the phoneme follows the uniqueness point, the faster it is detected. Uniqueness points for the current stimuli were held constant at 3 (i.e., the third phoneme from onset, C2, served as the point in which the speaker could determine if it was a specific known word or a new word). Values were calculated using FONRYE searchable phonetic dictionary software (Mlinar, 2010; available at http://www.languagebits.com/?=682/) based on the British English Example Pronunciations dictionary (BEEP: Robinson, 1996).

In terms of syllable boundary clarity, Wheeldon and Levelt (2002) noted that certain medial clusters during silent phoneme monitoring may be prone to ambisyllabicity (i.e., medial phonemes shifting between onset and coda of adjacent syllables due to syllabification). To decrease the likelihood of ambisyllabicity or syllabification during the encoding process, all but one medial cluster in each set in the current study are illegal in both onset and coda position in the English language[2] (Randall & Redford, 2005; Treiman & Zukowski, 1990; Treiman et al., 1992). As shown in Table 3, the present stimuli do not differ in lexical, phonological, or phonetic properties.

3.2.2 Phoneme selection

Target phonemes were presented auditorally and in isolation, rather than orthographically, to decrease the possibility that participants would identify the presence of the visual grapheme within a target nonword, rather than monitor the phonological position. As such, target phonemes were selected based on four exclusionary criteria.

First, target phonemes were not included if it did not occur in all positions (i.e., onset, medial, and coda) in the English language (e.g., [h, j, ŋ]). Second, target phonemes were not included if aural identification in isolation was difficult without inclusion of additional acoustic properties which also cue word position (i.e., aspirated vs. non-aspirated voiceless consonants). Third, consonants that were difficult to discriminate in certain positions without an accompanying vowel (i.e., voiced stops, rhotics) were not included to prevent coarticulatory input that may cue position, or provide a CV match or mismatch with target stimuli that may facilitate or impede reaction time responses. Finally, phonemes with alternative grapheme representations were

[2] Exceptions are /lz/ and /lʃ/, both legal in coda position.

avoided due to the inhibitory effect of orthographic redundancy on reaction time during phoneme monitoring tasks (Damian & Bowers, 2003; Dijkstra, Frauenfelder, & Schreuder, 1993). For example, /s/ could be spelled as "s" or "c", /ʤ/ as "g" or "j". In addition, medial /s/ phonemes are commonly perceived, and perhaps produced, in an ambisyllabic manner in the medial position (Treiman et al., 1992) were avoided to reduce the possible confound of ambiguous segmental encoding at the syllable boundary.

Of the remaining consonants that did not meet exclusionary criteria, six target phonemes were selected that included liquids, nasals, affricates and fricatives: [l, m, ʃ, v, z, f]. If phonemes were similar in manner of articulation and difficult to discriminate from each other in isolation, one was removed to increase auditory identification (e.g., although both /m/ and /n/ met criteria, only /m/ was included). Two remaining voiced fricatives [v, z] were included. Although these share voicing and manner of articulation, research has found 85% to 100% discrimination of these phonemes in isolation when duration and amplitude are sufficient (>40 ms, > 10 dB: Pirello, Blumstein, & Kurowski, 1997). Finally, first-syllable vowels were balanced for duration by assigning six tense and six lax vowels to each set of nonwords. Inclusion of both tense and lax vowels for first-syllable vowels allowed examination of whether duration of the vowel, rather than stress, contributed to the C1-C2 difference. All second-syllable vowels were tense to maintain balance across nonword stimuli. Consonants and vowels did not occur twice within a given target nonword.

A complete list of nonword stimuli are listed in Table 4. Each of the six target phonemes ([l, m, ʃ, f, v, z]) occupied each of the four consonants positions (C1, C2, C3, C4) twice and occurred eight times total across the 12 nonword stimuli.

3.2.3 Stimuli recording

Nonword and phoneme stimuli were recorded by a female native monolingual Standard American English speaker with no history of speech, language, or hearing disorders from Eastern Washington State (North American Western dialect: Labov, Ash, & Boberg, 2006). Stimuli were recorded in a quiet, sound treated room with a microphone placed approximately 12 inches from the speaker's mouth. Nonword stimuli and acoustic targets were recorded using Kay Elemetrics Computerized Speech Lab connected to a Dell computer. All digital files were sampled at a 22050-kHz sampling rate and 16-bit quantization.

Audio files for tone series stimuli were created using open-source, online sine tone generator (AudioCheck©; available at http://www.audiocheck.net/). Stimuli were compiled using open-source online digital audio editor program (Audacity© version 1.2.6; available at http://audactiy.surgeforce.net).

3.2.4 Block design

Twelve experimental blocks were created, one for each target nonword. Blocks included one nonword target (bisyllabic CVCCVC) and three monosyllabic CVC nonword foils. Monosyllabic foils were chosen to prevent potential priming of syllabic stress pattern. Inclusion of three foils allowed target phonemes to appear in at least two nonwords within a block and prevent process of elimination and/or "anticipation" strategies between target presentation and nonword cue. Together, the three nonword foils contained all six target phonemes.

To avoid any additional potential priming effects, a phoneme that occupied the C1 or C3 position in target nonword did not occupy the onset position of any of the three foils. Likewise, C2 and C4 phonemes of the target word did not occupy the final phoneme of any of the three foils, and vowels within foils did not overlap with vowels in target nonwords. Vowels were also constructed to balance the number of tense or lax initial vowels of target nonwords and each block had two tense initial vowels and two lax initial vowels across four words. For a list of target nonwords and corresponding foils, see Table 4.

3.3 PROCEDURES

Participants were seen during two sessions. The first session consisted of (a) description of study and written consent, (b) completion of intake questionnaire, (c) hearing, vision and handedness screening, (d) speech and language tasks, and (e) baseline reaction time and tone series tasks. The second session included the following: training tasks and silent phoneme monitoring tasks. Each session lasted approximately one and a half hours. Brief rest periods were provided between blocks to avoid fatigue or boredom, and increase comfort of the participant. A 15-minute break was provided after the sixth block, halfway through the session, for the same reasons.

All procedures were conducted by a certified speech-language pathologist in a clinical setting at the University of Texas Speech and Hearing Center, or if necessary, conducted in a suitable location, such as a library meeting room, that met the necessary parameters of the study (i.e., isolated, quiet). During the training and experimental trials, participants were positioned in a chair in front of the laptop, head approximately 18 to 20" from the screen, with fingers resting on pre-assigned "Yes" and "No" buttons on keyboard. Manual responses for the reaction time task, tone series task, and silent phoneme monitoring task were recorded using stimulus presentation software

(SuperLab Pro 4.5: Cedrus Software, 2012) on a Samsung Chronos laptop with 16" screen. Verbal responses during training and testing phases, as well as speech sample and verbal responses during phonological assessments were recorded using a Zoom Q2 audio/video recorder.

Manual "yes" and "no" responses were recorded using the "p" and "q" buttons on keyboard, respectively. If the participant reported left-hand dominance, "yes" and "no" button assignment was reversed prior to beginning any training or experimental trials, to ensure that reaction times for specific response were not influenced by use of non-dominant hand. "Yes" and "No" labels to identify the keyboard button were present and reversed if needed.

3.3.1 Phoneme discrimination task

Before training and experimental tasks began, participants were oriented to listening and identifying isolated target phonemes. During this brief trial, participants were instructed to "Listen and watch for the sound and corresponding letter. No response is required." After instruction, all target phonemes were simultaneously presented with corresponding grapheme for 2000 ms each in random order. Both the uppercase and lowercase letter was presented for each sound, resulting in 12 auditory and visual exposures to each phoneme. This phase occurred once, prior to training and experimental tasks, and lasted approximately one minute.

3.3.2 Experimental blocks

3.3.2.1 Training task

Prior to each silent phoneme monitoring trial, a training task for each nonword token was completed in the following order: familiarization, learning, and test trials, similar to the training phase described by Levelt and colleagues (Levelt & Wheeldon, 1994; Cholin et al., 2006; Cholin et al., 2011). These training phases were repeated twice prior to experimental trials.

3.3.2.2 Familiarization phase

During the familiarization phase, participants were presented with four auditory nonwords within a block (i.e., one target nonword, three foil nonwords) presented simultaneously with an orthographic representation of the nonword in one of the four corners on the computer screen. Participants were instructed to "Repeat the word after you hear and see it in one of the four corners."

The purpose of orthographic representation was twofold. First, given the potential effects of grapheme-phoneme incongruence on reaction time during phoneme identification tasks (Damian & Bowers, 2003; Dijkstra et al., 1993), simultaneous presentation of written word and auditory production further clarified grapheme-phoneme association within unfamiliar nonwords. Second, orthographic presentation was provided to reinforce stress assignment of novel stimuli. During nonword training, stressed syllables were presented in capital letters, and unstressed syllables in lower case letter (e.g., "mazFOOV"). Each nonword was preceded by an orienting cross in the center of the screen for 300 ms, followed by audio-visual presentation of the nonword for 3000 ms. Next, the orienting cross was displayed and the next nonword was presented.

Training trials requiring verbal responses were self-paced to accommodate for possible disfluent responses during familiarization and test phases. All four nonwords (one target nonword, three foils) were each presented four times, resulting in 16 total responses (i.e., four responses to the target nonword, and four responses to each foil).

Order of presentation during the familiarization phase was randomized to minimize serial recall during experimental tasks. Accuracy of responses was recorded throughout the study by external audio-video equipment and online scoring by examiner to allow offline inter- and intra-rater reliability.

3.3.2.3 Practice phase

During the practice phase, participants listened to auditory presentations of the same four stimuli. However, instead of orthographic cues, a neutral visual icon (i.e., 2 in. x 2 in. picture of a speaker) was presented simultaneously in all four corners. Participants were instructed to “Point to the corner associated with the word you hear.”

The purpose of the practice phase was to allow the participant further practice associating auditory stimuli with visual location without the support of orthographic input. Each of the four words was presented four times in random order for 3000 ms per token, resulting in 16 total responses (i.e., four responses to the target nonword, four responses to each foil). Accuracy was recorded by audio-visual equipment and examiner for reliability purposes.

3.3.2.4 Test phase

During the test phase, participants saw only the visual icon in one of the four corners on the screen. Participants were instructed to "Say the word associated with the corner of the screen when the speaker appears."

The purpose of the test phase was to assess the participants' ability to recall the nonword based solely on the neutral visual icon in a specific screen location, and without support of auditory or orthographic cues. Similar to the practice phase, each of the four words was presented four times in random order for 3000 ms per token, resulting in 16 total responses (i.e., four responses to the target nonword, four responses to each foil). Accuracy was recorded by audio-visual equipment and examiner for reliability purposes. After completion of this initial training phase, the participant had been exposed to each of the four nonwords 48 times (i.e., 12 exposures to target nonword, 12 exposures to each of the three foils).

3.3.2.5 Repeated training

After familiarization, practice, and tests phases were completed, the entire training task was repeated 2 to 4 times to allow additional practice and assure accurate recall of nonwords during upcoming experimental trials. During this second training task, each of the four nonwords was presented twice, resulting in 24 additional exposures in the second training (i.e., six for the target nonword, six for each of the three foils). Initial and subsequent training resulted in 72 total trials (i.e., 18 for the target nonword, 18 for each of the three foils). If the participant did identify all four nonwords with 100% accuracy during the second test phase, the second version of the training phase was repeated until 100% response accuracy was achieved during the test phase or participant had completed four training phases.

3.3.3 Silent phoneme monitoring task

During the experimental phase, each of the 12 blocks was presented in randomized order and included a training task, followed by the experimental task. Each block lasted at least 10 minutes, depending on the amount of training required to meet criteria. Each participant was comfortably seated approximately 18 to 20" in front of the laptop monitor and wearing headphones. Instructions were read aloud and simultaneously presented as written instructions on the monitor. Manual responses were recorded using the assigned "Yes" and "No" buttons on the keyboard.

3.3.3.1 Warm-up

Participants first completed eight practice trials to ensure comfort with the silent phoneme monitoring task and comprehension of instructions prior to the experimental trials. Participants were informed that this is a practice round and encouraged to ask questions for clarification if needed. Each participant then saw the following written instructions, also read aloud by the examiner: "You will hear a sound, then see a speaker icon in one of the four corners. Do not say the word aloud. If the sound was in the word, press 'Yes'. If not, press 'No'. Press Enter to get started." During the eight warm-up trials, icons representing each of the four nonwords were displayed twice, and all six target phonemes were presented at least once. Accuracy was scored online by the examiner. Similar to the training phase, if the participants' verbal or manual response was inaccurate on more than one trial, or expressed uncertainty with the task, the warm-up round was repeated until 100% accuracy was achieved and comfort with the task was reported.

Each trial within a block occurred in the following sequence. First, the participant saw a “Ready?” screen which advanced upon pressing the ‘Yes’ button. An orienting cross appeared in the center of the screen for 500 ms. The phoneme target was then presented via headphones for approximately 50 ms with the orienting cross on the screen. The orienting cross remained on the screen for an additional 900 ms, followed by the speaker icon in one of the four corners of the monitor.

Manual reaction time responses were recorded as the duration between the onset of the speaker icon until “Yes” or “No” button was pressed. After either button was pressed, or 3000 ms had elapsed, the participant was prompted via written instructions to “Say the word aloud. Press ’Yes’ to continue”, which triggered the beginning of the next trial starting at the “Ready?” screen. This final screen was self-paced and accuracy or verbal production was recorded by examiner and audio-visual equipment to ensure the participant was thinking of the appropriate word.

If a verbal response was incorrect by one or more phonemes, assigned inaccurate syllabic stress, or the participant responds “Yes” or “No” incorrectly, the trial was considered an error. See Figure 6 for graphic illustration of events during silent phoneme monitoring trials.

3.3.3.2 Silent phoneme monitoring

After completion of the training and warm-up trials, the participant completed the experimental silent phoneme monitoring trials within a block. During the silent phoneme monitoring task, participants were given instructions identical to the previous warm-up phase. Participants were encouraged to take short breaks if needed during self-paced "Ready?" screens. Sequence of events was identical to warm-up phase. Phonemes to be monitored occurred in one of four consonant positions within nonword stimuli (i.e., C1, C2, C3 or C4) or one of three foils.

Each experimental block consisted of 12 trials. Within each block, each phoneme was heard twice. All phonemes received both a 'Yes' and 'No' response to prevent anticipation or guessing from the participant. Target nonwords appeared six times (four "Yes" responses for each C1-C4 position, two "No" responses for phonemes not present). The three foils appeared twice and fluctuated in the number of Yes/No responses, as foils served to balance the number of "Yes/No" responses across the block (i.e., six "Yes" responses, six "No" responses within each block).

The sequence of trials within blocks were structured to ensure that (a) the same target phonemes were not presented on consecutive trials, (b) the same nonword was not presented on consecutive trials, and (c) no distinguishable "Yes/No" pattern could be detected. However, the order of blocks was randomized and order of presentation of stimuli was not identical across blocks. Once 12 trials of a block were completed, the next nonword block began.

To reduce the potential for visual habituation or expectancy, a target nonword appeared in each of the four corners of the screen three times across all 12 blocks. For each consonant position (C1, C2, C3, C4), all 22 participants had the opportunity to provide 12 "Yes" tokens (i.e. true positive), for a total of 132 true positive tokens per consonant position (i.e., C1, C2, C3, C4) and were considered during final analyses.

3.4 ANALYSES

3.4.1 Latencies

The purpose of Experiment 1 was to determine the influence of metrical property of initial stress on the speed and accuracy of phonological encoding in AWS and AWNS. To assess reaction time latencies for nonwords with initial stress, a 2x4 repeated measures mixed-model ANOVA was conducted, with talker group (i.e., AWS, AWNS) as the between-groups factor, and phoneme position latencies (i.e., C1-C2-C3-C4) as the within-groups factor. Planned pairwise comparisons were conducted to examine mean latencies of consonants flanking initial stress (i.e., C1 and C2) within and between talker groups.

3.4.2 Errors

To examine error data, three separate one-way ANCOVAs were conducted for three separate error types (i.e., false negatives, phonemic errors, and stress errors). The independent variable was talker group (i.e., AWNS, AWNS) and the dependent variable was error rate, with participant as the covariate factor to control for individual differences.

Individual alpha levels were set at .05 for ANOVAs, ANCOVA, and pairwise comparisons. All planned and post-hoc comparisons used the Bonferroni adjusted *p*-values, and all ANOVAs that did not meet assumptions of sphericity, the Greenhouse-Geisser adjusted *F*-values were reported.

3.4.3 Speed-accuracy tradeoff

Finally, possible speed-accuracy tradeoffs for mean errors (i.e., false negatives, phonemic errors, and stress errors) and SLDs were examined for AWNS and AWS. A 2x2 mixed-model ANCOVA was conducted with accuracy (i.e., accurate response, error response) and talker group (AWS, AWNS) as between group factors, and participant as the covariate factor. Paired-sample t-tests were conducted to examine speed-accuracy trade-offs between and within groups.

3.5 Results

3.5.1 Age, baseline reaction time, and pre-test scores

Table 5 shows the mean and SDs for each talker group for age, handedness, nine pre-experimental phonological tasks, and baseline reaction times. Independent t-tests found no significant differences in age (t[20] = -0.91 , p = .374), handedness scores (t[20] = -0.12, p = .904), or baseline reaction time (t[20] = -0.27, p = .789).

In addition, no group differences were observed in eight of the nine phonological subtests, including nonword repetition, t[20] = 0.50, p = .624; onset identification of real words or nonwords, (t[20] = 0.61, p = .546; t[20] = 1.08, p = .294); nonword onset generation t[20] = 0.22, p = .831; rhyme identification, t[20] = 0.45, p = .660; rhyme generation, t[20] = 0.63, p = .538; forward or backward digit span (t[20] = 0.20, p = .841; t[20] = 1.71, p = .102). However, talker groups demonstrated a significant difference in onset generation of real word, t[20] = 2.34, p = .024, with AWNS exhibiting slightly better segmentation skills (M = 19.73, SD = 0.47) than AWS (M = 18.82, SD = 0.87).

As suggested by Sasisekaran et al. (2006), one approach to address the subtle differences in segmentation skills is to re-examine response time latencies using onset generation scores as a covariate factor. Due to near-ceiling effects in both groups, onset generation scores were transformed into *z*-scores based on the mean and SD for each talker group. Results did not differ from those obtained in the initial analysis. That is, response latencies by position remained significant within group, $F(3, 17) = 15.30$, $p < .000$, $\eta\rho^2 = .734$, with no significant differences between groups, $F < 1$, or group by position interaction, $F < 1$. These data do not support differences in onset generation abilities as a contributing factor in observed differences during experimental tasks.

3.5.2 Tone series data

Participant responses during the tone series task were assessed using a mixed model repeated measures ANOVA, with talker group as the between-group factor (i.e., AWNS, AWS) and tone position (i.e., tone 1, tone 2, tone 3, and tone 4) as the within-groups factor. Prior to analysis, data were inspected for the presence of reaction time outliers. Of the 1,056 true positive responses (i.e., 528 AWNS, 528 AWS), 5.02% (n = 53) were more than 2 SDs above or below the mean reaction time for that participant in that position (i.e., 2.36% AWNS, n = 25; 2.65% AWS, n = 28), within the guideline of <12% for elimination of reaction time outliers suggested by Ratcliff (1993). Of the 1,003 viable responses, 5.98% (n = 60) false negative responses were identified and excluded from analysis (i.e., 3.29% AWNS, n = 33; 2.69% AWS, n = 27). Final reaction time analysis was conducted on the remaining 943 viable responses (i.e., AWNS, n = 470; AWS, n = 473). Greenhouse-Geisser *F*-values were used if assumptions of sphericity were violated, and any post-hoc comparisons were conducted with Bonferroni adjusted values.

3.5.2.1 Latencies

As illustrated in Figure 7, a significant main effect for position was found $F(3, 18) = 62.00$, $p < .001$, $\eta\rho^2 = .756$, but no main group effect ($F < 1$) or group by position interaction was revealed ($F < 1$). Post-hoc tests revealed that, for both groups, tones were identified at significantly longer latencies as series position increased, although latencies between position 1 (AWNS: $M = 521.40$, $SE = 54.68$; AWS: $M = 522.05$, $SE = 54.68$) and position 2 (AWNS: $M = 551.30$, $SE = 35.56$; AWS: $M = 564.81$, $SE = 35.56$) did not reach significance for either group.

3.5.2.2 Accuracy

Error analysis was conducted using the 1,003 viable responses which included the false negative errors reported ($n = 60$; AWNS: $n = 33$; AWS: $n = 27$). As illustrated in Figure 8, and similar to reaction time data, a significant main effect for position was found $F(3, 18) = 9.75$, $p < .001$, $\eta\rho^2 = .328$, but no main group effect ($F < 1$) or group by position interaction was revealed ($F < 1$). Post-hoc comparisons revealed non-significant differences in accuracy between groups, with only AWNS identifying tones at position 3 ($M = 8.55\%$, $SE = 2.47\%$) and position 4 ($M = 12.91\%$, $SE = 3.86\%$) with significantly lower accuracy than position 1, which was identified with 100% accuracy.

3.5.3 Silent phoneme monitoring

3.5.3.1 Unusable data

The purpose of the study was to assess reaction time latencies and accuracy of AWS and AWNS during silent phoneme monitoring. Similar to Sasisekaran et al. (2006), data were removed from reaction time and error analyses and considered unusable if the following criteria were met:

(a) **No Response:** participant provided no manual response, or initiation of fluent verbal response more 3000 ms after button press

(b) **Overlapping Verbal Response:** verbal response overlapped manual response; this criterion was included to increase the likelihood that reaction times were the product of covert processing rather than articulatory processing and production

(c) **Outlier**: manual response exceeded 2 SDs above or below the participants' consonant position-specific mean reaction time for fluent, accurate responses

From the initial 1,056 tokens collected (AWNS: n = 528; AWS: n = 528), 22 tokens (2.08%) were excluded based on non-response (AWNS: n = 14; AWS: n = 8); 30 tokens (2.84%) were excluded based on overlapping verbal response (AWNS: n = 25; AWS: n = 5); and 54 tokens (5.11%) were considered outliers (AWNS: n = 32; AWS: n = 22). For one AWNS, manual responses were not recorded for one nonword block (n = 4 responses; 0.38%)

In sum, from the initial 1,056 tokens collected, 110 tokens (10.42%) were considered unusable prior to all subsequent analyses. The final data corpus included 946 usable tokens (AWNS: *n* = 453; AWS: *n* = 493). See Table 6 for detailed breakdown of excluded tokens.

3.5.3.2 Excluded data

To reduce likelihood that reaction time was affected by inaccurate retrieval, processing, or identification of phonemes within the target nonword, reaction time data were based on accurate nonverbal monitoring accompanied by phonetically accurate, fluent verbal responses. Individual tokens were excluded from the reaction time analysis, (but included in the subsequent error data and disfluency analyses), if they met the following criteria:

(a) **False Negative:** participant manually responded ‘no’ when target phoneme was present

(b) **Phonemic Error:** verbal response included one or more phonemic error

(c) **Stress Error:** verbal response included inaccurate syllabic stress

(d) **Stuttered Response:** verbal response contained a stuttering-like disfluency (SLD: i.e., sound-syllable repetition, audible sound prolongation, and/or inaudible sound prolongation; Yairi & Ambrose, 2005).

From the usable data corpus (*N* = 946: AWNS: *n* = 453; AWS: *n* = 493), 105 tokens (11.10%) were excluded based on false negative manual responses (AWNS: *n* = 39; AWS: *n* = 66); 42 tokens (4.44%) were excluded based on phonemic error during verbal response (AWNS: n = 11; AWS: n = 31); and 5 tokens were excluded based on stress error during verbal response (AWNS: n = 3; AWS: n = 2).

In addition, verbal responses produced with an SLD were also excluded. As expected, only AWS produced SLDs during verbal production. Verbal responses that were produced with an SLD were excluded and examined in separate, subsequent one-way analysis within AWS. Of the 946 usable tokens, a total of 22 tokens (2.33%) were excluded based on stuttered verbal response (AWNS: n = 0; AWS: n = 22).

In sum, from the usable 946 tokens collected, 174 tokens (26.81%) were excluded from the reaction time analysis based on error response. The final data corpus used included 772 fluent, accurate tokens (AWNS: n = 400; AWS: n = 372). See Table 6 for detailed summary of excluded tokens.

3.5.4 Reaction time latencies

As depicted in Figure 9, a mixed-model repeated measure ANOVA was conducted to assess the reaction time latencies of AWNS and AWS during silent phoneme monitoring of C1 and C2, consonants flanking initial stress assignment in bisyllabic nonwords. There was no significant group by position interaction ($F < 1$), and no significant main effect for talker group ($F < 1$). However, there was a significant main effect for consonant position, Wilks' Lamba = .31, F (3, 18) = 13.29, $p < .001$, $\eta\rho^2 = .689$.

Planned comparisons indicated mean latencies between talker groups did not significantly differ for C1 or C2. However, planned within-group comparisons revealed significantly longer latencies for C2 (M = 1100.21, SE = 102.59) relative to C1 (M = 891.23, SE = 81.09) in the AWNS groups, but not the AWS group (C1: M = 988.00, SE =

81.09; C2: *M* = 1095.64, *SE* = 102.59). See Table 7 and Figure 9 for means and *CIs* for AWNS and AWS per consonant position.

Given that all stimuli were novel words to participants and considerable training was required, the likelihood of sub-vocal rehearsal may have been heightened in the present study (e.g., Baddeley, 1983; Baddeley et al., 1975). To further confirm that latency differences did not reflect monitoring of phonetic code during subvocal rehearsal, additional analyses were conducted to examine potential differences between C1 and C2 latencies.

During stimuli construction, phonetic quality of the initial vowel for each of the 12 nonwords was balanced (i.e., six tense vowels, six lax vowels; Shriberg & Kent, 2002). If participants were monitoring phonetic code, rather than phonological code, latency differences between C1 and C2 could reflect the phonetic duration of the initial vowel. In specific, C2 for nonwords with tense vowels would conceivably result in longer latencies than C2 for nonwords with lax vowels.

A mixed-model 2x2x2 repeated measures ANOVA was conducted, with consonant position (i.e., C1, C2) as the within-group factor, and vowel quality (i.e., tense, lax) and talker group (i.e., AWS, AWNS) as between-group factors. Results indicate the expected main effect of position $F(3, 39) = 18.87$, $p < .000$, $\eta\rho^2 = .33$, with both groups C2 latencies longer than C1. No significant position by vowel quality interaction was observed, ($F < 1$), nor three way interaction (i.e., talker group x position x vowel quality; $F < 1$). Planned comparison of C2 latencies by vowel quality were not significant for AWNS (tense: *M* = 1078.28, *SE* = 109.62; lax: *M* = 1078.37, *SE* = 109.62) or AWS (tense: *M* = 1060.25, *SE* = 114.97; lax: *M* = 1072.86, *SE* = 109.65). In sum, regardless of quality of preceding vowel, C2 latencies did not significantly differ.

3.5.5 Errors

As described, three different types of errors were coded during the silent phoneme monitoring task: false negative, phonemic errors, and stress errors. Each error type was examined in separate one-way ANCOVA, with talker group (AWNS, AWS) as the independent variable, error rate as the dependent variable, and participant as the covariate factor. See Figure 10 for means and *SE* for each group per error type.

3.5.5.1 False negative response

Adjusting for individual differences of participants, no significant main effect found between stuttering and non-stuttering adults, F (1, 21) = 1.437, p = .245, $\eta\rho^2$ = .070. Data in the present study was collapsed across phoneme position during initial analysis; however, based on raw error data (see Table 6), it is possible that greater number of false negative errors may have occurred relative to specific consonant position, as reported in Sasisekaran et al. (2006).

A secondary analysis was conducted to more closely compare present data across studies. A 2x4 mixed-model repeated measures ANOVA was completed with consonant position as the within-group factor (i.e., C1, C2, C3, and C4), talker group (i.e., AWS, AWNS) as the between-group factor, and false negative response rate as the dependent variable. No significant differences between groups at any position were detected. An overall significant main effect for position was found, F(3, 20) = 2.17, p = .026, $\eta\rho^2$ = .164. Closer examination found both groups exhibited greater false negative errors with increasing consonant positions. However, significant differences were found only between C1 (M = 8.10%, SE = 3.21%) and C4 (M = 18.47%, SE = 4.64%) in adults who stutter. Non-stuttering adults did not exhibit this significant increase in errors at the C4 position, or at any position.

3.5.5.2 Phonemic errors

Similar to false negatives, no significant main effect of group was revealed, ($F < 1$) after adjusting for individual difference of participant.

3.5.5.3 Stress errors

Similar to phoneme and false negative errors, no significant main effect of group was revealed, ($F < 1$) after adjusting for individual difference of participant.

3.5.6 Speed-accuracy tradeoff

A significant main effect was found for talker group $F(1, 907) = 11.10$, $p < .001$, $\eta\rho^2 = .012$, as well as accuracy, $F(1, 907) = 97.35$, $p < .001$, $\eta\rho^2 = .097$, with both groups responding faster during inaccurate responses. However, a significant talker groups by accuracy interaction was also found, $F(1, 907) = 6.54$, $p = .011$, $\eta\rho^2 = .007$. Paired t-tests revealed longer latencies for inaccurate responses for AWS ($M = 650.82$, $SE = 50.78$) than AWNS ($M = 415.49$, $SE = 55.54$), but no reaction time differences during accurate responses (AWS: $M = 966.47$, $SE = 36.38$; AWNS: $M = 959.62$, $SE = 35.45$; see Figure 11).

Chapter 4: Silent phoneme monitoring of nonwords – Syllable boundary

4.1 METHODS

4.1.1 Participants

Similar to Experiment 1, Experiment 2 also included 22 adults (AWS = 11, age range: 19 to 28 years; AWNS = 11, age range: 18 to 36 years). These participants did not participate in the first experiment. All participants were from central Texas and surrounding areas with monolingual or native-like proficiency in Standard American English. Each talker group was balanced for gender (7 males, 4 females in each group) and as closely as possible for age (+/- 14 years or less). Participants were naïve to the specific variables of the study. Experiment 2 was also approved by the Institutional Review Board at the University of Texas at Austin. Written consent was obtained from each participant prior to participation and each participant was provided compensation.

4.1.1.1 Inclusionary criteria

Intake procedure, inclusionary criteria, and exclusionary criteria in Experiment 2 were identical to that of Experiment 1. Of the initial 37 participants (17 AWS, 20 AWNS) recruited for Experiment 2, two participants (1 AWNS, 1 AWNS) were not included due to current medication (e.g., Strattera), and two additional AWS participants were not included due to significant neurological or medical history (e.g., history of seizures, motor difficulties). Two participants (1 AWS, 1 AWNS) participants were not included due to non-native-like proficiency in English.

4.1.1.2 Exclusionary criteria

Of the remaining 31 participants (13 AWS, 18 AWNS) who met the inclusion criteria, three participants (1 AWS, 2 AWNS) did not pass the hearing assessment and were excluded from the study. Three additional participants (1 AWS, 2 AWNS) were excluded based on baseline manual reaction times that exceeded 2 SD (*z*-scores) from the mean of their talker group. The remaining 25 participants (11 AWS, 14 AWNS) were balanced for gender, then age, as closely as possible based on the distribution within the AWS group. Male AWNS of the most frequent age (i.e., 18-19 years old) were randomized and the first three were selected for removal. The final participant pool resulted in 22 participants (11 AWS, 11 AWNS: 7 males and 4 females in each group), similar to Experiment 1.

4.1.1.3 Talker group classification

Criteria for talker group classification were identical to Experiment 1. Of the 11 participants who self-identified as an AWS, eight had received a formal diagnosis of stuttering from a certified speech-language pathologist. The remaining three participants who had not received a diagnosis, but self-identified as an AWS, exhibited a score of 2 or higher on a stuttering severity scale (O'Brian et al., 2004) during either the conversational or reading speech samples. The 11 AWNS participants did not self-identify as an individual who stutters, had no prior diagnosis of stuttering, and received a severity score of 1 (i.e., "no stuttering") during conversational and reading samples. See Tables 8 and 9 for description of individual AWNS and AWS participants.

4.1.1.4 Reliability

Inter-rater reliability of stuttering severity was determined by the author and the same undergraduate research assistant used in Experiment 1. Six of the 22 participants were selected at random and two-way mixed model inter-class coefficient was conducted to assess reliability of stuttering severity within and across speech samples. Intra-class coefficients were conducted by the author approximately one month after initial scoring.

For conversational samples, severity ratings for AWNS participants was exact for 100% of the participants (*n* = 3), all of whom received a score of 1 (i.e., "*no stuttering*"). For AWS, inter-rater reliability for conversational samples was exact for 66% of the participants (*n* = 2), and within one point for the remaining participant, with all participants receiving a score of 2 or higher (range: 2 = "*very mild stuttering*" to 5 = "*moderate stuttering*"). Inter-class coefficient was .93 between raters. Intra-rater reliability was exact for 100% of the participants, indicating perfect intra-class correlation (1.00).

For reading samples, severity ratings for AWNS participants was exact for 100% of the participants (*n* = 3), all of whom received a score of 1 (i.e., "*no stuttering*"). For AWS, inter-rater reliability for reading passage was within one point for 100% participants (*n* = 3), with all participants receiving a score of 2 or higher (range: 2 = "*very mild stuttering*" to 5 = "*moderate stuttering*"). Inter-class coefficient was .80 between raters. Intra-rater reliability was within one point for 66% (*n* = 2) of the participants, and exact for the remaining participant, with .93 intra-class correlation. For both speech samples from AWS participants (*n* = 6 samples) inter-class coefficient was .82 between raters, with .95 intra-class correlation coefficient (severity range: 2 = “*very mild stuttering*” to 5 = “*moderate stuttering*”).

4.2 Experimental design and procedure

Experiment 2 was identical to Experiment 1 in experimental design, procedures, stimuli recording protocol and phonetic structure of stimuli. The critical difference between studies was the assignment of stress within the nonword stimuli. As in Schiller (2005), stress was assigned to the second syllable of the CVCCVC bisyllabic nonword, exposing syllable boundary assignment as the metrical property first encountered by the participant during phonological encoding and within the silent phoneme monitoring task.

4.3 Analyses

In addition to the latency, error, and speed-accuracy trade-off analyses conducted in Experiment 1, two additional analyses were conducted in Experiment 2 using data from Experiment 1. First, examination of SLD production based on the metrical properties of nonword stimuli was possible by comparing the SLDs from words with initial stress (Experiment 1) and without initial stress (Experiment 2). A mixed-model repeated measures ANOVA was conducted to perform this analysis, with consonant position as the within-groups factor (i.e., C1, C2, C3, and C4) and metrical properties (i.e., initial stress, syllable boundary) as the between-groups factor. Second, comparison of speed-accuracy tradeoffs of SLDs with different metrical properties were compared using a 2x2 ANCOVA, with fluency (i.e., fluent response, stuttered response) and metrical properties (i.e., initial stress, syllable boundary) as between group factors, and participant as the covariate factor.

Across analyses, and similar to Experiment 1, individual alpha levels were set at .05 for all ANOVA, ANCOVA, and pairwise comparisons. Greenhouse-Geisser *p*-values were used if violation of sphericity occurred, and Bonferroni adjustments were reported for any planned or post-hoc comparisons.

4.4 Results

4.4.1 Age, baseline reaction time, and pre-test scores

Table 10 shows the mean and SDs for each talker group for age, handedness, nine pre-experimental phonological tasks, and baseline reaction times. Independent t-tests found no significant differences in age ($t[20] = 0.68$, $p = .506$), handedness scores ($t[20] = 0.64$, $p = .531$), or baseline reaction time ($t[20] = -1.22$, $p = .236$).

In addition, no group differences were observed in eight of the nine phonological subtests, including nonword repetition, $t[20] = -0.13$, $p = .896$; onset identification of real words or nonwords, ($t[20] = -0.30$, $p = .764$; $t[20] = 0.43$, $p = .674$); onset generation for real words or nonwords ($t[20] = 0.00$, $p = 1$; $t[20] = -.71$, $p = .488$); rhyme identification, $t[20] = 0.00$, $p = 1$; rhyme generation, $t[20] = -1.07$, $p = .298$; or backward digit span, $t[20] = -1.47$, $p = .159$. However, talker groups demonstrated a significant difference in forward digit span ($t[20] = -2.92$, $p = .010$), with AWS exhibiting slightly better phonological working memory ($M = 11.09$, $SD = 2.26$) than AWNS ($M = 8.82$, $SD = 1.25$). Data indicate that adults who stutter outperformed typically fluent adults in their ability to maintain phonological information in short-term memory. This difference is somewhat unexpected in light of previous studies which suggest phonological weaknesses in adults who stutter, particularly at the level of phonological working memory (see Bajaj, 2007, for review).

Similar to Experiment 1, these differences were examined relative to performance on experimental tasks during secondary analysis of experimental latency data, with forward digit span performance as a covariate factor. Experimental outcomes did not differ from initial analysis upon inclusion of covariate. That is, response latencies remained significant by position within groups, $F(3, 17) = 5.97$, $p = .006$, $\eta\rho^2 = .513$, and between groups performance, $F(1, 19) = 1.39$, $p = .253$, $\eta\rho^2 = .068$, and groups by position interaction, ($F < 1$), remained non-significant. Data do not suggest that advanced phonological working memory skills in adults who stutter was a primary contributor to silent phoneme monitoring responses in the current study.

4.4.2 Tone series data

Similar to Experiment 1, participant responses during the tone series task were assessed using a mixed model repeated measures ANOVA, with talker group as the between-group factor (i.e., AWNS, AWS) and tone position (i.e., tone 1, tone 2, tone 3, and tone 4) as the within-groups factor. Prior to analysis, data were inspected for the presence of reaction time outliers. Of the 1,056 true positive responses (i.e., 528 AWNS, 528 AWS), 4.73% ($n = 50$) were more than 2 SDs above or below the mean reaction time for that participant in that position (i.e., 2.18% AWNS, $n = 23$; 2.56% AWS, $n = 27$), within the guideline of <12% for elimination of reaction time outliers suggested by Ratcliff (1993). Of the remaining 1,006 viable responses, 3.58% ($n = 36$) false negative responses were identified and excluded from analysis (i.e., 2.39% AWNS, $n = 24$; 1.19% AWS, $n = 12$). Final reaction time analysis was conducted on the remaining

970 viable responses (i.e., AWNS, n = 481; AWS, n = 489). Greenhouse-Geisser values were used if assumptions of sphericity were violated, and any post-hoc comparisons were conducted with Bonferroni adjusted values.

As illustrated in Figure 12, a significant main effect for position was found F (3, 18) = 245.00, $p < .001$, $\eta\rho^2 = .925$, but no main group effect, $F(1, 20) = 2.487$, $p = .130$, $\eta\rho^2 = .111$, or group by position interaction was revealed ($F < 1$). Post-hoc revealed, for both groups, tones were identified at significantly longer latencies as serial position increased.

Error analysis was conducted on the 1,006 viable responses that included the false negative errors excluded from reaction time analysis (n = 36; AWNS: n = 24; AWS: n = 12). As illustrated in Figure 13, and similar to reaction time data, a significant main effect for position was found F (3, 18) = 9.98, $p < .001$, $\eta\rho^2 = .333$, but no main group effect $F(1, 20) = 2.06$, $p = .166$, $\eta\rho^2 = .094$, or group by position interaction was revealed ($F < 1$). Post-hoc comparisons revealed non-significant differences in accuracy between groups, with only AWNS identifying tones at position 4 (M = 11.82%, SE = 2.73%), with significantly lower accuracy than position 2 (M = 0.82%, SE = 0.00%) and position 1, which was identified with 100% accuracy.

4.4.3 Silent phoneme monitoring

The purpose of Experiment 2 was to assess reaction time latencies and accuracy of AWS and AWNS during silent monitoring of phonemes at the syllable boundary of nonwords. Similar to Experiment 1, data were removed from reaction time and error analyses and considered unusable if the following criteria were met:

(a) **No Response:** participant provided no manual response, or initiation of fluent verbal response more 3000 ms after button press

(b) **Overlapping Verbal Response:** verbal response overlapped manual response; this criterion was included to increase the likelihood that reaction times were the product of covert processing rather than articulatory processing and production

(c) **Outlier**: manual response exceeded 2 SDs above or below the participants' consonant position-specific mean reaction time for fluent, accurate responses

From the initial 1,056 tokens collected (AWNS: *n* = 528; AWS: *n* = 528), 20 tokens (1.89%) were excluded based on non-response (AWNS: *n* = 4; AWS: *n* = 16); 15 tokens (1.42%) were excluded based on overlapping verbal response (AWNS: *n* = 6; AWS: *n* = 9); and 33 tokens (3.13%) were considered outliers (AWNS: *n* = 18; AWS: *n* = 15).

In sum, from the initial 1,056 tokens collected, 68 tokens (6.44%) were considered unusable prior to analyses. The final data corpus included 988 usable tokens (AWNS: *n* = 500; AWS: *n* = 488). See Table 11 for detailed breakdown of excluded tokens.

4.4.3.1 Excluded data

Similar to Experiment 1, the following errors were excluded from reaction time analysis:

(a) **False Negative:** participant manually responded 'no' when target phoneme was present

(b) **Phonemic Error:** verbal response included one or more phonemic error

(c) **Stress Error:** verbal response included inaccurate syllabic stress

(d) **Stuttered Response:** verbal response contained a stuttering-like disfluency (SLD: i.e., sound-syllable repetition, audible sound prolongation, and/or inaudible sound prolongation; Yairi & Ambrose, 2005).

From the usable data corpus (*N* = 988: AWNS: *n* = 500; AWS: *n* = 488), 137 tokens (13.87%) were excluded based on false negative manual responses (AWNS: *n* = 59; AWS: *n* = 78); 58 tokens (5.87%) were excluded based on phonemic error during verbal response (AWNS: *n* = 16; AWS: *n* = 48); and 33 tokens were excluded based on stress error during verbal response (AWNS: *n* = 5; AWS: *n* = 28).

In addition, and similar to Experiment 1, verbal responses produced with an SLD were also excluded. Of the 988 usable tokens, a total of 8 tokens (0.81%) were excluded based on stuttered verbal response (AWNS: *n* = 0; AWS: *n* = 8).

In sum, from the usable 988 tokens collected, 236 tokens (23.89%) were excluded from the reaction time analysis based on error response. The final data corpus used included 770 fluent, accurate tokens (AWNS: *n* = 420; AWS: *n* = 350). See Table 11 for detailed summary of excluded tokens.

4.4.4 Reaction time latencies

A mixed-model repeated measures ANOVA was conducted to assess the reaction time latencies of AWNS and AWS during silent phoneme monitoring of C2 and C3, consonants flanking the syllable boundary in bisyllabic nonwords. No significant group by position interaction was revealed ($F < 1$), nor was a significant main effect for talker group found, (*F* < 1). However, there was a significant main effect for consonant position, Wilks' Lamba = .38, F (3, 18) = 9.82, p < .001, $\eta\rho^2$ = .621.

Planned comparisons indicated mean latencies between talker groups did not significantly differ for C2 or C3. However, planned within-group comparisons revealed significantly longer latencies between C3 (*M* = 1342.34, *SE* = 129.00) relative to C2 (*M* = 1223.72, *SE* = 108.35) in the AWS groups. AWNS did not exhibit a significant difference between C2 and C3 (C2: *M* = 1095.71, *SE* = 108.35; C3: *M* = 1122.50, *SE* = 129.00). See Table 12 and Figure 14 for means and SE for AWNS and AWS per consonant position.

Similar to Experiment 1, additional analyses were conducted to assess the possibility that participants were monitoring the phonetic speech code of subvocal rehearsal, rather than syllabified output generated by phonological encoding. As in Experiment 1, quality of initial vowels (i.e., tense and lax) was included as an independent factor in a mixed-model 2x2x2 repeated measures ANOVA to assess whether phonetic vowel duration influenced the participants' non-verbal responses at C2 and C3. Results were similar to those of Experiment 1. That is, no significant main effects for vowel quality, *F* <1, or talker group, $F(1, 39) = 1.27$, $p = .266$, $\eta\rho^2 = .032$, nor group x vowel quality interaction, *F* < 1, were found. As in the initial analysis, differences between C2 and C3 remained significant, $F(1, 39) = 9.37$, $p = .004$, $\eta\rho^2 = .194$. Further, planned comparisons did not reveal a significant difference in C3 latencies based on vowel quality for adults who stutter (tense: *M* = 1136.15, *SE* = 124.58; lax: *M* = 1218.70, *SE* = 118.78) or adults who do not (tense: *M* = 1132.02, *SE* = 118.78; lax: *M* = 1051.98, *SE* = 118.78).

4.4.5 Errors

As in Experiment 1, three types of errors (i.e., false negative, phonemic errors, and stress errors) was examined in separate one-way ANCOVA, with talker group (AWNS, AWS) as the independent variable, error rate as the dependent variable, and participant as the covariate factor. See Figure 15 for means and *SE* for each group per error type.

4.4.5.1 False negative response

Similar to Experiment 1, no significant main effect of group for false negative errors was revealed, F (1, 21) = 1.30, p = .269, $\eta\rho^2$ = .064, after adjusting for individual difference of participant.

4.4.5.2 Phonemic errors

A significant main effect found between groups was found, F (1, 21) = 4.69, p = .043, $\eta\rho^2$ = .198, with AWS exhibiting overall greater phonemic errors (M = 23.25%, SE = 3.58%) than AWNS (M = 12.27%, SE = 3.58%).

4.4.5.3 Stress errors

A significant main effect found between groups was found, F (1, 21) = 5.17, p = .035, $\eta\rho^2$ = .214, with AWS exhibiting overall greater phonemic errors (M = 16.37%, SE = 2.97%) than AWNS (M = 6.78%, SE = 2.97%).

4.4.6 Stuttered responses

As expected, analysis of SLDs was limited to AWS, as AWNS produced no SLDs during verbal responses. No significant main effect was found for consonant position, (F

< 1), nor was a significant consonant position by metrical property interaction revealed during analysis, $F(3, 18) = 1.687$, $p = .205$, $\eta\rho^2 = .078$. Finally, no significant main effect for metrical properties of nonwords (i.e., initial stress, initial syllable boundary) was found ($F < 1$). See Figure 16 for illustration of consonant position and metrical properties in relation to SLD production.

4.4.7 Speed-accuracy tradeoff

Similar to Experiment 1, possible speed-accuracy tradeoffs for errors and SLDs were examined for AWNS and AWS. Two 2x2 mixed model ANCOVAs were conducted with talker group (AWS, AWNS) as between group factors and participant as the covariate factor in both analyses, with accuracy (i.e., accurate response, error response) as the within-group factor in the error analysis, and fluency (i.e., fluent response, stuttered response) as the within groups factors in the SLD analysis. Paired-sample t-tests were conducted to examine speed-accuracy trade-offs between and within groups.

4.4.7.1 Errors

Speed of response for error data found a significant main effect for group $F(1, 954) = 16.92$, $p < .001$, $\eta\rho^2 = .018$, as well as accuracy, $F(1, 954) = 78.84$, $p < .001$, $\eta\rho^2 = .077$, with both talker groups responding faster during inaccurate responses. Groups by accuracy interaction did not reach significance, $F(1, 954) = 1.376$, $p = .241$, $\eta\rho^2 = .001$. However, in addition to the longer latencies for inaccurate responses for AWS ($M = 769.96$, $SE = 45.45$) than AWNS ($M = 539.40$, $SE = 53.04$), similar to Experiment 1, paired t-tests also revealed AWS significantly longer latencies for accurate responses (M = 1106.99.50, $SE = 39.11$) than AWNS ($M = 978.75$, $SE = 34.73$; see Figure 11).

4.4.7.2 Fluency

Finally, speed of response during fluent and stuttered responses in AWS were compared in conjunction with data from Experiment 1 to examine if metrical configuration of nonwords (i.e., initial stress, initial syllable boundary) contributed to speed-accuracy trade-offs. As depicted in Figure 17, a main significant effect of fluency was revealed, $F(1, 600) = 7.571$, $p = .006$, $\eta\rho^2 = .013$, but no significant main effect for metrical property (F <1) or fluency x metrical property interaction was found (F <1). Data indicate responses produced with an SLD were associated with longer reaction times during silent phoneme monitoring tasks regardless of metrical configuration (initial stress: M = 1367.47, SE = 151.25; syllable boundary: M = 1421.93, SE = 208.02) relative to fluent responses (initial stress: M = 961.98, SE = 33.95; syllable boundary: M = 1103.198, SE = 36.70).

Chapter 5: Discussion

The purpose of this study was to examine the influence of metrical properties on phonological encoding in adults who do and do not stutter. Reaction time latencies and non-verbal response errors were assessed during a silent phoneme monitoring task. The fluency and accuracy of post-trial verbal responses were also assessed. In Experiment 1, adults who stutter were predicted to exhibit greater latency differences between C1 and C2 than non-stuttering adults due to additional processing time required during initial stress assignment. Similarly, in Experiment 2, adults who stutter were predicted to exhibit greater latency differences between C2 and C3 than non-stuttering adults due to additional processing time required during syllable boundary assignment. No within group predictions unique to each experiment were made relative to the fluency and/or accuracy of responses but the adults who stutter were predicted to be less fluent and less accurate than adults who do not stutter.

Data indicate that the speed and accuracy of phoneme monitoring was influenced by metrical properties of speech in adults who stutter in a manner distinct from typically fluent adults. Three main findings were observed across experiments. In Experiment 1, contrary to predictions, adults who stutter identified initial phonemes (i.e., C1) of stressed syllable more slowly than typically fluent adults, and with speeds comparable to the syllable-final phonemes (i.e., C2). In Experiment 2, consistent with predictions, adults who stutter identified phonemes following the syllable boundary (i.e., C3) significantly slower than the preceding phoneme (i.e., C2). In addition, significantly greater phonemic and stress-based errors were observed for adults who stutter during post-trial responses in Experiment 2.

In contrast to adults who stutter, typically fluent adults monitored stimuli with initial and non-initial stress with almost identical speed and accuracy. C1-C2 latency differences were significant regardless of metrical configuration. Syllable boundary latencies (i.e., C2-C3) were non-significant, and error rate did not significantly differ based on metrical properties of stimuli. Findings suggest the influence of metrical properties during phonological encoding was unique to adults who stutter.

5.1 Research question 1: Does the metrical property of initial stress assignment contribute to slower phonological encoding in adults who stutter relative to typically fluent adults?

5.1.1 Main finding: Delayed encoding of initial segment

During initial stressed syllables, participants who stutter exhibited an unexpected lack of significance between C1 and C2 phonemes. Non-significant differences were characterized by delayed identification of initial phoneme (i.e., C1), rather than the predicted delayed latency of syllable-final phoneme (i.e., C2). Data were not consistent with Sasisekaran et al. (2006), which reported significant differences between C1 and C2 for both talker groups when monitoring words with initial stress. Adults who stutter also exhibited increased C1-C2 differences in the absence of metrical stress (Experiment 2). Dissimilar patterns in the presence or absence of initial stress are inconsistent with Burger and Wijnen's (1999) finding that adults who stutter maintained similar incremental encoding irrespective of initial stress. Thus, data across Experiment 1 and 2 suggest that metrical stress exerts a unique influence on the phonological encoding of adults who stutter compared to typically fluent adults, albeit not in the manner originally predicted.

5.1.2 Primary interpretation: Holistic versus incremental encoding

At face value, differing patterns of C1-C2 latencies in the presence or absence of initial stressed syllables could be interpreted to reflect atypical metrical encoding in adults who stutter. However, the unexpected influence of stress on C1, but not C2, during initial stress warrants reconsideration of our hypothesis. Difficulties encoding metrical stress would be reflected by prolonged C2 latencies only if segmental encoding was relatively intact and operated as predicted in Levelt et al.'s (1999) model. It is important to note that Levelt et al.'s model was derived from data collected from fluent adults with (presumably) no history of compromised phonological abilities. Given that phonological difficulties are a well-documented phenomenon in adults who stutter, present data may instead reflect atypical segmental encoding abilities in adults who stutter that become more evident during metrical stress assignment.

One theoretical model of stuttering, Byrd et al.'s (2007) holistic encoding theory, suggests that phonemes within a syllable are represented not as individual segments, but as a holistic unit composed of less detailed segmental information. If this is the case, comparable latencies identifying C1 and C2 phonemes may indicate segmental information was not readily available before the initiation of left-to-right syllabification. As described by Brooks and MacWhinney (2000), transition from holistic to incremental encoding during early development allows left-to-right, incremental assembly of speech to occur. Lack of incremental encoding of the first syllable, as supported by non-significant differences between C1 and C2 latencies, suggests that holistic processing may still be employed during speech planning in adults who stutter.

To date, direct investigations of holistic encoding in individuals who stutter have been restricted to children. Byrd et al. (2007) provided evidence for over-reliance on holistic encoding in children who stutter at later ages than typically fluent peers. Speech reaction times were recorded for children who do and do not stutter (aged 3 to 5 years old) as they named pictures that appeared on a computer monitor. Prior to picture presentation, an auditory prime was heard that corresponded with either the initial phoneme of the picture name (i.e., C-) or the remaining portion of the word (e.g., -VC). Results indicated that non-stuttering children exhibited the expected shift from holistic to incremental processing as language abilities developed. Children who stutter, on the other hand, maintained faster speech reaction times with holistic -VC primes at later ages than developmentally expected. Thus, children who stutter may continue to rely on less detailed representations of word forms, a pattern that may persist beyond childhood.

Arnold et al. (2006) provide further support for over-reliance on holistic encoding in children who stutter. Authors employed the same priming paradigm described in Byrd et al. (2007) but in addition to reaction time data, they also collected event-related potential (ERP) data. Greater ERP amplitudes were considered to reflect increased neural processing effort during priming tasks. Behavioral findings replicated those of Byrd et al., in that children who stutter continued to benefit from non-incremental primes at later ages. In addition, children who stutter exhibited reduced neural activity when presented with holistic primes, and increased neural activity during incremental primes, at both younger and older ages. In contrast, fluent peers demonstrated reduced neural activity when presented with holistic primes at younger ages, and reduced neural activity when presented with incremental primes at older ages. Findings suggest that incremental priming required less processing effort in non-stuttering children as language system matured, while incremental primes required greater processing demand in children who stutter, regardless of age.

Data from Byrd et al. (2007) and Arnold et al. (2006) provide indirect evidence of over-reliance on holistic encoding in adults who stutter. Although shifts from holistic to incremental lexical representation of words are most evident during early vocabulary development (e.g., Brooks & MacWhinney, 2000; Charles-Luce & Luce, 1990; Walley, Smith, & Juscyk, 1986), holistic representations do not necessarily disappear with chronological age. As described by Metsala (1997), shifts from holistic to incremental representations occur on an item-by-item basis rather than a system-wide change. In her acoustic gating study, Metsala found typically fluent adults required greater phonetic-acoustic information of initial segments to identify target words of low frequency compared to words of high frequency. Findings support that shifts from holistic to incremental encoding occurs as a product of increased vocabulary size and prior exposure to words. The nonwords developed for the present study bear minimal resemblance to real words (i.e., low neighborhood density, syllable frequency, phonotactic probability, and word-likeness). Thus, present stimuli likely increased the use of initial holistic representation in individuals who stutter given the demonstrated over-reliance on holistic representation in childhood.

Indirect evidence of holistic processing exists for adults who stutter. For example, Sussman, Byrd, and Guitar (2010) examined the acoustic properties of fluent and stuttered tokens that included initial consonant-vowel (CV) onsets. Results indicated that the phonetic properties between initial consonant and vowels of stuttered tokens remained relatively intact and similar to non-stuttered CV tokens. Authors interpreted findings to suggest that phonetic properties were preserved once phonological plans become available to the articulatory system. An alternative explanation is that the phonological plans were not segmented upon initial retrieval. That is, the global phonological plan, or at least the initial portion (i.e., CV-) was transferred to the phonetic encoding system as a single holistic unit. Lack of atypical co-articulation patterns may reflect undisrupted phonetic programming, but does not rule out that phonological information was undivided from initial retrieval to overt articulation.

Byrd, Sheng, Gkalitsiou and Ratner (2013) recently found that adults who stutter had significantly greater difficulty accurately recalling lists of words that were phonologically related (e.g., wet, watt, wit…) as opposed to semantically related (e.g., damp, humid, moist…). This difference suggests that persons who stutter have marked difficulty with the verbatim trace, but that they do not appear to have difficulty with the gist trace. When recalling words that are phonologically related the listener must rely on the distinct sound segments that comprise the words (i.e., the verbatim trace). If the listener has difficulty segmenting the sounds in the words, he/she would have difficulty encoding lists of words that are maximally similar in phonological properties. On the other hand, if the words are semantically related such that they are minimally phonologically similar but relate to one another by a specific semantic theme, then any difficulty with phonological encoding of the words would be subverted by the ability to determine the gist trace (i.e., thematic relationship) among the words.

In the present study across both Experiment 1 and 2, adults who stutter were required to recall verbatim trace of novel stimuli without benefit of thematic representation. Thus, based on findings of Byrd et al.'s (2013) study, comparable latencies identifying C1 and C2 in the present data may arguably reflect greater difficulty identifying or recalling segmental information in the absence of semantic input.

Taken together, previous accounts of segmental processing difficulties in individuals who stutter suggest that holistic encoding and under specification of the phonological code may persist into adulthood. Findings correspond with the observed lack of C1-C2 differentiation in the present study. To date, previous stuttering literature has concentrated on the contribution of segmental properties during phonological encoding, but there has been limited emphasis on metrical properties of phonological encoding. Although it is difficult to determine the precise contribution of metrical encoding in the context of compromised segmental encoding, data from the present study allow preliminary interpretations.

In Experiment 1, C1-C2 phoneme monitoring latencies did not significantly differ in the presence of metrical stress. In contrast, significant C1-C2 latencies occurred on the unstressed initial syllable in Experiment 2. This latter finding suggests that in the *absence* of initial stress, incremental encoding was able to occur. This begs the question: why would metrical stress disrupt incremental encoding (as observed in Experiment 1) while lack of metrical stress would not (as observed in Experiment 2)?

If, as proposed, syllables were retrieved as a holistic unit, individual segments may not be available or fully segmented prior to syllabification. For example, during typical incremental encoding of a /CVC/ syllable, the phonological system would activate each individual segment [C] [V] [C] prior to syllabification. Phonological information available within a holistic plan may be less segmented. If holistic representations are retrieved, the phonological plans available prior to syllabification may include [CV-C], [C

–VC], or the entire unified syllable [CVC]. In the latter scenario, additional time to assign stress to the intervening vowel would also delay the availability of associated C1 and/or C2 phonemes. This interpretation is congruent with non-significant C1-C2 data in adults who stutter in Experiment 1.

In theory, if the persistent use of holistic encoding results in a comparable delay to initial, medial, and/or final segments in the initial stressed syllables, Natke et al.'s (2004) predictions may require expansion, particularly if initiation of execution is in fact relatively invariant (e.g., Logan, 2003; Logan & Conture, 1997). Postma and Kolk (1993) discussed the intra-syllabic loci of difficulty that would result in specific disfluency types. For example, if the target word was "backpack," delayed access to C1 might result in inaudible blocks (i.e., --- "BACKpack"), delayed access to initial vowel may result in prolongations or repetitions (i.e., prolongations, "B---ACKpack"; "B-B-B-BACKpack), and delayed access to C2 may result in consonant+vowel repetitions (i.e., repetition, "BA-BA-BACKpack"). Although the purpose of the present study was to observe phonological encoding in the absence of overt speech, performance during the present nonverbal monitoring task lends support to the observed patterns during verbal output.

On the other hand, significant C1-C2 differences observed on unstressed initial syllables in Experiment 2 suggests segmental encoding remains incremental in the absence of metrical stress. No predictions were made regarding C1-C2 latencies in the unstressed initial syllable. Nonetheless, the contrast between Experiment 1 and 2 suggests that the presence of initial stress increases the likelihood of holistic encoding in adults who stutter. One possible interpretation is that retrieval of holistic representations, when they occur, maintain initial [CV-] as a bound unit rather than other instantiations (i.e., [C-VC] or [CVC]). If this is the case, the absence of additional processing time required for stress assignment on the initial vowel would allow C1 to be monitored more quickly and C2 more slowly.

Alternatively, data may suggest that adults who stutter typically access segments independently ([C-V-C]) during phonological encoding, similar to typically fluent adults. However, given the high frequency of initial stress within Germanic languages (e.g., English, Dutch, German) and the tendency of adults who stutter to store phonological code in a holistic manner early in life, adults who stutter may maintain two competing representations of the same phonological code: a fully segmented representation (i.e., [C-V-C]) and a holistic representation (i.e., [CV-], [-VC], [CVC]). These explanations remain speculative. At a minimum, the dissimilarity observed between C1-C2 latencies in stressed and unstressed contexts suggest that metrical encoding has the *potential* to alter segmental encoding in adults who stutter relative to fluent adults. That being said, unexpected findings in the present study warrant cautious interpretation and alternative accounts of observed patterns.

5.1.3 Alternative explanations

5.1.3.1 Benefit of C1 delay

Reaction time data reported in the present study were collected prior to fluent post-trial responses. Although not considered during initial prediction, it is possible that adults who stutter allow additional processing time prior to encoding the first syllable to increase the likelihood of fluent output. In other words, a delay in the activation of the C1 segment may, in fact, promote fluency in adults who stutter.

As discussed by Schiller (2005), increased time allowed between C1-C2 allows all remaining segmental and metrical properties time to become fully activated in preparation for phonological encoding (i.e., syllable boundary, C3, C4). If this time allowance occurred prior to C1 encoding, all segmental and metrical properties within the word would benefit from additional processing time. Increased processing time prior to assembly of the initial phoneme would allow the stress bearing vowel and following segment (i.e., C2) to become immediately available. This additional time would also account for the attenuated C1-C2 latency difference observed in the present study. From a clinical application perspective, this interpretation is congruent with fluency-enhancing techniques which allow greater time at or prior to the initiation of speech (e.g., easy onset, light articulatory touch, and rhythmic speech: Guitar, 2014; Van Riper, 1973).

5.1.3.2 Stuttered vs. fluent post-trial responses

As noted by Hartsuiker, Kolk, and Lickely (2005), interpretation of data from participants who stutter in the absence of stuttered speech presents an additional challenge when interpreting data from using nonverbal paradigms (e.g., Burger & Wijnen, 1999; Sasisekaran et al., 2006; Wijnen & Boers, 1994). In specific, reliance of reaction time data in the absence of speech production may not capture the aberrant phonological encoding thought to occur during or prior to stuttered speech. It is possible that, in the present study, exclusion of reaction time data associated with disfluent post-trial productions inadvertently excluded the phonological encoding differences that contribute to stuttered speech.

This alternative explanation becomes plausible upon consideration of response time data from fluent and stuttered post-trial responses in Experiment 1 (see Figure 18). Too few stuttered tokens were available to allow for meaningful statistical analysis. However, descriptive data depict a considerable delay in C2 planning prior to stuttered responses (*M* = 1721.61, *SE* = 224.54) relative to C2 latencies of fluent responses (*M* = 1095.64, *SE* = 102.59) and C1 latencies during stuttered responses (*M* = 1152.40, *SE* = 205.31). As discussed in the literature review, pronounced latency differences between C1-C2 in adults who stutter due to slowed metrical encoding would theoretically present an ideal environment for single-sound repetitions and prolongations to occur (Natke et al., 2004). It is perhaps not surprising that the predicted pattern was more evident upon analysis of performance associated with stuttered speech.

Although the number of stuttered tokens during single-word responses (5.58%, 22 of 394 words) was greater than the standard percentage of stuttered words criteria for 300-word connected speech samples (3%; Yairi & Ambrose, 2005), it is premature to draw this conclusion as the total sample size in the present study was disproportionately low compared to fluent responses. Interpretation remains speculative until a greater number of stuttered tokens become available in future studies. For example, nonverbal identification of the present stimuli within a syntactic frame would provide an encoding setting that is more representative of the environment in which stuttering is most likely to occur – longer, more complex utterances (for review see Zackheim & Conture, 2003).

5.2 Research Question 2: Does the metrical property of syllable boundary assignment, in the absence of initial stress, contribute to slower phonological encoding in adults who stutter relative to typically fluent adults?

5.2.1 Main finding 1: Delayed encoding at the syllable boundary

Data from Experiment 2 suggest that adults who stutter require significantly more time to encode the syllable boundary in the absence of initial stress. Increased latencies when monitoring consonants after the syllabic boundary in adults who stutter are in agreement with the prediction that processing metrical properties of speech may be more challenging within this clinical population.

5.2.2 Primary interpretation: Prolonged metrical encoding independent of segmental encoding

Schiller (2005) provides the only comparative literature of expected silent phoneme monitoring performance at the syllable boundary in the presence or absence of initial stress. He reported that in the absence of initial stress, the unique influence of additional processing time required to assign the syllable boundary was exposed. When initial syllable stress was present, the additional time required to assign initial stress appears to allow all subsequent segmental and metrical properties to become fully activated and available for assignment. This "plateau effect" is observable across multiple studies which included stimuli with initial stress.

Table 13 illustrates the C1-C2 and C2-C3 latencies across studies that used stimuli with non-initial stress, or mixed stimuli sets (i.e., initial and non-initial stress, as significant latencies at both points were assumed to reflect first encountered metrical properties).[3] The gradual decrease of C2-C3 significance with increasing C1-C2 latencies reveals a potential temporal “trade-off” when encoding C1 to C3 in typically fluent adults within a relatively finite time frame (i.e., 115 to 193 ms). Non-stuttering adults may require additional time to process the syllable boundary, but this may have been masked by increased C1-C2 latencies. It should be noted, however, that the greatest differences between C1-C2 and C2-C3 is observed in studies that used stimuli with initial stress only, suggesting that metrical stress is a major contributor, but not an exclusive factor, in prolonged C1-C2 latencies.

In contrast, as depicted in Table 14, adults who stutter do not appear to follow the same tradeoff pattern. In the present study adults who stutter exhibited a significant mean C2-C3 latency difference of 118 ms, even in the presence of significantly increased C1-C2 latencies (i.e., 157 ms). Data indicate that increased time during C1-C2 encoding is not sufficient to allow ample time to encode the syllable boundary. Thus, perhaps as predicted, encoding syllable boundaries may be particularly difficult for adults who stutter.

From a cross-linguistic perspective, data are in agreement with the findings of Matsumoto-Shimamori and colleagues (Matsumoto-Shimamori et al., 2011; Shimamori & Ito, 2006; 2007; 2010). In this series of studies, children who stutter exhibited greater stuttering when target nonwords composed of similar phonetic segments contained a syllable boundary closer to onset (e.g., /ki.pu/) compared to those that did not (e.g., /kip.u:/). Findings also align with Natke et al. (2004) who reported unstressed syllables which precede stressed syllables were more likely to result in monosyllabic repetitions.

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[3] Data from Jansma and Schiller (2004) was excluded as C1-C2 latencies were not available for CVCVC stimuli.

Monosyllabic repetitions may occur due indicate delayed availability of the second syllable due to increased processing time at the syllable boundary. Although direct correlation between nonverbal tasks and overt stuttering patterns are tentative, data from both paradigms support the notion that individuals who stutter are more prone to breakdowns during syllable boundary assignment.

Chang and colleagues (Chang, 2013; Chang, Erickson, Ambrose, Hasegawa-Johnson, & Ludlow, 2008) provide neurobiological support for difficulty in syllable transitions in adults who stutter. In short, white matter insufficiency between the premotor cortex and putamen impedes transmission of copies for presently executed motor commands. As a result, the motor program for the currently executed syllable program is not fully inhibited, and the upcoming syllable cannot be fully activated. One potential outcome of slowed activation is a delayed initiation of upcoming syllables, perhaps at the syllable boundary.

Neural abnormalities in adults who stutter were recently simulated by neural network models of speech production. Using their GODIVA neural network model, Civier, Bullock, Max, and Guenther (2009) hypothesized that transition to the upcoming syllable (i.e., across the syllable boundary) would be markedly impaired due to white matter insufficiency within the left precentral gyrus (Chang et al., 2008). Ciever and colleagues simulated this scenario using the target word /go.diˈ,və/ [second syllable stress]. The reported result was an inaudible block on the onset of the second, stressed syllable. This motoric outcome serves as a viable alternative to the monosyllabic repetition prior to a stressed syllable reported by Natke et al. (2004).

The methodology used to complete neurobiological investigations of stuttering has been inconsistent across studies, contributing to diffuse, somewhat equivocal findings (for review, see Bloodstein & Bernstein Ratner, 2008). Nevertheless, evidence from Chang and colleagues (2013; 2008) combined with simulations by Civier et al. (2009) lend neurobiological support to the theory that initiation of a syllable presents particular difficulty in individuals who stutter.

5.2.3 Alternative explanation

5.2.3.1 Phonotactic properties

According to Levelt et al. (1999), both segmental and metrical properties are required to assemble the phonological speech plan. Present data suggest that assignment of syllable boundaries occur even in the presence of relatively uncompromised segmental encoding. However, because both segmental and metrical properties are required during assembly, it is possible difficulties processing segmental properties may further exacerbate delayed metrical encoding at the syllable boundary.

For example, phonotactic properties of the medial cluster may influence the speed of encoding. This possibility was explored in a subsequent analysis conducted by Wheeldon and Morgan (2002). In their study, CVCCVC stimuli were comprised of words with “clear” syllable assignment (i.e., clusters that are illegal in onset or coda position within a syllable: *lit.mus* is provided as an example), words with “likely” syllable assignment (i.e., medial cluster assumed to be assigned to the onset of the second, stress-bearing syllable; *dol.phin* is provided as an example), and words with ambisyllabic third consonants (i.e., consonants thought to occupy both the coda of the first syllable and onset of the second syllable; *pel[m]et* is provided as an example).

Wheeldon and Morgan (2002) noted that the phonotactic properties of the medial cluster may have contributed to diminished C2-C3 latencies (i.e., 63 ms) relative to C1-

C2 latencies (i.e., 109 ms). During subsequent re-analysis, Wheeldon and Morgan examined this possibility by removing stimuli with the ‘clearest’ syllable boundaries. Results indicated while C1-C2 latencies remained significant (i.e., 114 ms), C2-C3 latencies were reduced by half (i.e., 29 ms) and failed to reach significance.

Wheeldon and Morgan (2002) stated these findings suggest phonotactic properties contribute to the speed of encoding at the syllable boundary, but they did not elaborate on the precise nature of the interaction. The direction of change reported indicates that the inclusion of stimuli with clear syllable assignment *increased* C2-C3 latencies, and inclusion of stimuli with more ambiguous syllable assignment reduced the differences between C2 and C3. Data from typically fluent adults in Experiment 2 do not support this pattern of change. The nonword stimuli in Experiment 2 were composed almost entirely of medial clusters with clear syllable boundaries (i.e., 10/12 nonwords included medial clusters that were phonotactically illegal in onset or coda position within a syllable). Unlike Wheeldon and Morgan, results indicated relatively comparable C2-C3 differences (i.e., 27 ms) in typically fluent adults in the presence of medial clusters with clear syllable boundary assignment.

Although an interaction between phonotactic properties of segmental information and assignment of metrical information (i.e., syllable boundary) is a reasonable consideration, the pattern of influence remains unclear. Comparison of C2-C3 latency patterns for adults who stutter in Experiment 2, however, provide some support for an interaction between segmental and metrical properties. Given the potential difficulties accessing segmental properties in adults who stutter, retrieval of segments that rarely co-occur (i.e., low phonotactic probability) may have further delayed activation of segmental information. It is possible that the presence of less frequent stress patterns *in* *combination* with low frequency medial clusters may have prolonged C2-C3 latencies. In contrast, non-stuttering adults perhaps accessed low-frequency medial segments more easily due to robust segmental organization, resulting in relatively minimal interaction of segmental and metrical properties at the syllable boundary. For adults who stutter, inclusion of low-frequency medial clusters, defined as illegal in either onset or coda position and therefore lower in frequency within the language, may have increased C2-C3 latencies.

5.2.4 Main finding 2: Increased phonemic and stress-based errors

In Experiment 2, adults who stutter exhibited a significantly greater number of errors than non-stuttering adults. This pattern was observed during post-trial verbal responses and characterized by increased phonemic and stress assignment errors. Increased error rate was significantly higher for adults who stutter only when producing words in which stress was placed on the second syllable and the syllable boundary was the first-encountered metrical property.

5.2.5 Primary interpretation: Alternative metrical encoding due to weakness in working memory

Increased phonemic errors during words with non-default stress patterns may be most apparent during tasks which involve nonwords. Nonword tasks impose greater demand on phonological working memory. Individuals who stutter have demonstrated greater difficulties during nonword repetition tasks, a pattern thought to indicate poorer retention of segmental information (e.g., Byrd et al., 2012; Hakim & Ratner, 2004). For example, Hakim and Ratner administered to children who do and do not stutter a modified version of the four-syllable stimuli in Children's Test of Nonword Repetition (Gathercole, Willis, Baddeley, & Emslie, 1994), with stress assigned to the fourth syllable. Although both talker groups exhibited a greater number of errors than repeating the same nonwords with typical stress, children who stutter exhibited a greater number of phonemic errors. In addition, children who stutter also made 17 stress-assignment errors, while non-stuttering participant made 13 stress-assignment errors. None of the differences reported reached significance, but similar patterns across studies indicate atypical stress patterns further compromise the ability of participants who stutter to retain information in phonological working memory.

An intriguing outcome of the present study, also observed in Hakim and Ratner (2004), was the significant tendency for adults who stutter to produce stress-assignment errors (i.e., assign stress to the first syllable instead of second syllable). Stress-assignment errors are rare in the non-disordered population, and are typically associated with non-stuttering clinical populations (e.g., non-fluent aphasia, apraxia) or observed during early speech development. Given the reported weaknesses in phonological short-term memory reported in previous studies (see Bajaj, 2007 for review), it is possible the adults who stutter in the present study relied more heavily on default prosodic patterns to retain segmental information.

Morgan, Edwards, and Wheeldon (2013) reported a similar pattern for non-stuttering adults during serial recall of nonwords. In this study, bisyllabic nonwords were grouped based on stress pattern (i.e., trochaic, or STRONG-weak; and iambic, or weak-STRONG). Participants recalled a significantly higher percentage of nonwords with trochaic stress patterns than iambic. Morgan et al. interpreted findings to suggest non-stuttering adults recruit well-learned language-based properties, such as typical metrical stress patterns, to maintain phonological code in short-term memory. Similar recruitment may have occurred for the adults who stutter in the present study, but to a greater degree given the presumed subclinical differences in phonological working memory.

Difficulty retaining segmental and metrical information of nonwords with non-default stress pattern in adults who stutter was evident during training tasks in Experiment 2. Participants were required to produce the target word with phonemic accuracy and appropriate stress assignment prior to experimental tasks. Over-reliance on initial stress patterns when learning nonwords with non-initial stress may have contributed to the significantly greater amount of training required in adults who stutter. For Experiment 2, adults who stutter required a significantly higher number of prior exposures (M = 22.98; SE = 0.66) compared to typically fluent adults (M = 20.79; SE = .18). Increased training in adults who stutter provides preliminary support that reconfiguration to default metrical frame as a byproduct of compromised nonword recall abilities. Although previous research exists that indicate individuals who stutter have more difficulty recalling nonwords of atypical stress patterns (e.g., Hakim & Ratner, 2004), further research is required to determine the utility of default stress patterns on fluent, accurate speech production. At minimum, data across studies suggest that some participants who stutter produced default metrical frames during recall of novel speech code.

5.2.6 Alternative explanations

5.2.6.1 Disrupted retrieval of metrical frame

Nickels and Howard (1999) outlined the level of deficit that certain stress-related errors may represent. Authors describe stress-based error patterns within Levelt's (1989) framework of speech production and discuss two potential loci for stress-related errors. First, errors that occur on any unstressed syllable, regardless of position, would indicate deficits at the level of the mental syllabary due to mis-activation of stressed versus unstressed representations of the same phonological string. Second, errors of stress-assignment or omission of unstressed syllables during words with weak-STRONG stress pattern reflect corrupted representation or insufficient retrieval of stored metrical frames. In response, the phonological encoding system re-assigns default metrical patterns (i.e., STRONG-weak) in lieu of access to stored metrical frame[4].

Using these criteria, observed errors of stress-assignment in adults who stutter are indicative of loss or disrupted retrieval of the metrical frame during phonological encoding. Given the additional processing time observed at the syllable boundary (i.e., C2-C3) in adults who stutter, inadequate retrieval of the metrical frame during phonological spell-out may be a potential locus of difficulty in adults who stutter, in addition to the subtle differences in storage and retrieval of phonological properties (e.g., Anderson, 2007; Anderson & Byrd, 2008; Anderson, Wagovich, & Hall, 2006; Byrd et al., 2007; Byrd et al., 2012; Hakim & Ratner, 2004).

[4] Nickels and Howard (1999) also note vowel and syllable transposition errors as indicative of deficits at this level of processing. These predictions are contingent on segments being "marked" of stress assignment, a notion not supported in later instantiations of Levelt's model (Levelt et al., 1999).

5.3 Additional considerations across experiment 1 and 2

To review, the present study reported three main findings for adults who stutter: (1) segmental difficulties in the presence of initial stress assignment, (2) delayed assignment of syllable boundaries that were perhaps independent of segmental abilities, and (3) increased phonemic and stress-based errors on words in which stress was assigned to the second syllable. Although main and alternative interpretations of each were provided, the narrow margin of non-significance observed between C1-C2 in adults who stutter (p = 0.053) in Experiment 1, and unexpected lack of significant reaction time differences between talker groups across experiments, warrant closer investigation of individual variability of participants.

5.3.1 Individual differences

Variability amongst individuals who stutter is not a novel phenomenon, and is often considered a signature of performance within the stuttering population. With the wide range of variability reported for individuals who stutter in motoric performance (e.g., Peters, Hulstijn, & van Lieshout, 2000; Namasivayam & van Lieshout, 2011; Smits-Bandstra, de Nil, & Saint-Cyr, 2006; Smith, Goffman, Sasisekaran, & Weber-Fox, 2012), language abilities (e.g., Anderson & Conture, 2000; Coulter, Anderson, & Conture, 2009; Ntourou, Conture, & Lipsey, 2011), temperament (e.g., Eggers, de Nil, & van den Bergh, 2010; Karrass et al., 2006; Kefalianos, Onslow, Block, Menzies, & Reilly, 2012; Seery, Watkins, Mangelsdorf, & Shigeto, 2007), and stuttering itself (e.g., Meyers, 1986; Van Riper, 1982; Yaruss, 1997), perhaps the most unexpected finding would be invariant performance within a given sample of participants who stutter.

Anderson and Conture (2000) noted that measures of central tendency, while important, are often influenced by large variability and small sample size. In this study of language abilities in children who stutter, description of individual performance revealed the possibility of subgroups within the participant pool. An approach similar to Anderson and Conture would similarly inform the possibility of subgroups in the present data.

In Experiment 1, adults who stutter were originally predicted to exhibit prolonged latencies between C1 and C2 relative to fluent adults. Overall, the majority of typically fluent participants performed as predicted. Of the non-stuttering participants, 73% (8/11) exhibited C1-C2 differences greater than 100 ms, 18% (2/11) exhibited C1-C2 differences between 0 and 100 ms, and only one (9%) exhibited negative C1-C2 differences (i.e., mean C2 differences faster than C1). Adults who stutter exhibited a wider distribution of performance: 45% (5/11) exhibited C1-C2 differences above 100 ms, 18% (2/11) with C1-C2 differences between 0 and 100 ms, and 36% (4/11) exhibiting negative C1-C2 differences. Data suggest that while the majority of adults who stutter perform comparable to fluent adults, a subgroup exhibited mean C1 latencies that were equal or slower than C2. This proportion of participants may reflect a subgroup of adults who stutter who are more likely to retain more holistic encoding strategies.

Idiosyncratic performance of adults who stutter has been observed in previous studies of segmental encoding within initial stressed syllables (i.e., Burger & Wijnen, 1999; Wijnen & Boers, 1994). The primary motivation for Burger and Wijnen's study was to reduce the influence of individual variability observed in Wijnen and Boers with increased sample size. Despite these efforts and non-significant group differences, Burger and Wijnen noted that a number of participants did indeed benefit from CV-primes but not C- primes (pp. 100-101), indicating less incremental segmental encoding. Descriptive data provided by Burger and Wijnen (p. 100, Table 2) revealed a greater number of stuttering participants benefitted from CV- primes but not C- primes in the initial stress condition (5/15, 33%) and non-initial stress condition (3/15, 20%) relative to non-stuttering participants (initial stress: 2/15, 13%; non-initial stress, 1/15, 7%). Inconsistent performance of individuals within participant cohorts suggest that lack of group differences may be due, in part, to variant phonological encoding patterns within adults who stutter, or perhaps the existence of subgroups within the stuttering sample, compared to non-stuttering cohort.

Sasisekaran et al. (2006) reported a non-significant group by position interaction, but a significant main effect of position during silent phoneme monitoring tasks. These data indicate that C1-C2 latencies followed a similar trend in both groups (i.e., C1 was monitored significantly faster than all subsequent phonemes). Sasisekaran et al. did not include the means or standard error for individual positions within each talker group. Authors also did not complete pairwise comparisons between C1 and C2 latencies within each group. As such, precise comparison with data from the present study should be considered with caution.

Mean C1 latencies illustrated in Sasisekaran et al. (2006, Figure 2, p. 12) provides descriptive data about group performance at individual consonant positions. Adults who stutter were approximately 100 ms slower than typically fluent adults when monitoring phonemes in the C1 position during initial stressed syllables. Mean latencies are similar to the 97 ms difference at C1 observed between groups in the present study. Similar between-group latencies between studies, but dissimilar levels of significance, indicate that variance in performance may be a critical factor between studies. Taken together with the Wijnen's studies (Burger & Wijnen, 1999; Wijnen & Boers, 1994), measures of central tendency may not capture the relatively greater number of participants who stutter that exhibit variant and atypical patterns of phonological encoding.

In the present study, the variability of performance in adults who stutter becomes evident when contrasted with the remarkably stable performance of typically fluent adults. Figure 19 depicts the variability of mean response latencies per talker group at each consonant position during Experiment 1. Typically fluent adults' individual response times when monitoring phoneme in C1 position were restricted to 173.97 ms (min: 864.78 ms; max: 1038.75 ms). In contrast, adults who stutter exhibited a considerably wider range of variability when monitoring C1 (range of 1088.03 ms, min: 489.30 ms; max: 1577.33 ms). A similar trend was observed at all subsequent consonant positions, with adults who stutter exhibiting consistently wider ranges of variability relative to non-stuttering adults. Although the range increased across positions for typically fluent adults, the variability remained more restricted compared to adults who stutter.

To further examine the nature of this variability, Figures 20 and 21 depict the range of individual participant responses within each group at each consonant position in Experiment 1. Considerable overlap is observed across non-stuttering participants at both C1 and C2 positions. In contrast, individual participants who stutter performed with less stability and with greater heterogeneity between and within participants.

Greater variability in adults who stutter provides insight to the non-significant findings observed between C1 and C2 in the present study. Non-significant C1-C2 trend may reflect idiosyncratic phonological encoding abilities for within or between adults who stutter. Certain participants responded reliably within the response window observed in typically fluent adults, suggesting a subgroup of participants who stutter exhibited the expected incremental encoding time course. Other participants responded inconsistently, monitoring C1 with mean latencies slower than C2. This interpretation of present data suggests a subgroup of participants who stutter may exist for whom incremental encoding is compromised by metrical stress. However, marked differences in individual variation appeared to be unique to Experiment 1. As illustrated in Figure 22, both talker groups exhibit considerable inter- and intra-speaker variability (see Figures 23 and 24) when monitoring all phonemes (i.e., C1-C4) in words in which syllable-boundary was the first-encountered property.

5.3.2 C1-C2 monitoring in typically fluent adults

Contrary to predictions, significantly increased C1-C2 differences were observed irrespective of metrical stress in typically fluent adults. Findings are not congruent with Schiller (2005), who reported increased C1-C2 latencies in the presence of initial stress, and minimal C1-C2 difference in the absence of initial stress. Findings also contradict our initial interpretation of data reported by Sasisekaran et al. (2006), who found increased C1-C2 latencies in non-stuttering adults when silently monitoring stimuli comprised entirely of words with initial stress. However, findings are consistent with fluent adults in Burger and Wijnen's (1999) implicit priming study, in that left-to-right segmentation was maintained on initial syllables with and without stress. Taken together, increased C1-C2 latencies in typically fluent adults cannot be attributed exclusively to the presence of initial stress.

Initial interpretation of data suggests that metrical stress may not influence phonological encoding in non-stuttering adults. On the other hand, data do not altogether discount the influence of stress assignment during phonological encoding. Non-lexical status of stimuli may have altered the typical phonological processing pattern observed in non-stuttering adults. Although it is possible that metrical stress played a minimal role in C1-C2 latencies in non-stuttering adults, differences in performance within cohorts and methodological differences between studies warrant alternative interpretations.

Incremental encoding is central to Levelt et al.'s (1999) model of speech production. Wheeldon and colleagues (Wheeldon & Levelt, 1995; Wheeldon & Morgan, 2002) considered additional processing time observed between C1 and C2 to reflect the time required to encode metrical stress during the first syllable. Across these studies, all stimulus lists included words with initial and non-initial stress. In contrast to the present study, researchers did not compare stimuli of initial versus non-initial stress. Thus, significant C1-C2 latencies were attributed to the *co-occurrence* of initial stress, rather than direct manipulation of metrical properties. It is possible that increased C1-C2 latencies simply reflected the robust incremental nature of phonological encoding in typically fluent adults, regardless of metrical configuration.

Only Schiller (2005) contrasted phoneme monitoring latencies of words with initial and non-initial stress. Minimal C1-C2 differences were observed when participants monitored real word stimuli with non-initial stress. However, Schiller did not imply that C1-C2 latency differences would fail to exist in the absence of initial stress. Rather, data were used to illustrate the influence of metrical encoding on subsequent segmental and metrical properties of planned speech. If C1-C2 differences were non-existent, this pattern would counter Levelt et al.'s (1999) proposal model of incremental phonological encoding.

Additional experiments conducted within Schiller's (2005) study provide evidence for incremental encoding even in the absence of metrical properties. For example, in his second experiment (pp. 254-255), typically fluent participants monitored $C_1C_2VC_3.C_4V(C)$ bisyllabic real words with and without initial consonant clusters. Although stress demarcation was not reported, clusters occurred prior to the initial stress-bearing vowel. Results indicated that individual consonants within the initial cluster were monitored in an incremental fashion (i.e., C1 < C2; approximately 50 ms). Significance levels of C1-C2 differences were not discussed. Nonetheless, descriptive data suggest that metrical properties may protract incremental encoding of segments, but incremental encoding of phonemes occurs even in the absence of metrical encoding.

5.4 Additional considerations across present and past studies

To date, studies of silent phoneme monitoring performances only used real word stimuli. The adapted silent phoneme monitoring task used in the present study was developed to isolate, to the greatest degree possible, the level of phonological encoding in adults who do and do not stutter. This approach is effective in reducing the potential influence of lexical and semantic factors which may have impacted findings from previous studies (e.g., Sasisekaran et al., 2006; Wheeldon & Levelt, 1995). In addition, the present study provides original data to describe how silent monitoring of phonemes in real words and nonword may differ. However, the unique nature of this study also invites confounds not present in previous silent phoneme monitoring tasks that must be considered during interpretation of findings. Three potential contributing factors will be discussed relative to the present findings: task complexity, subvocal rehearsal, and the effects of increased training.

5.4.1 Task complexity

Sasisekaran et al. (2006) reported significant differences in C1-C2 latencies in adults who do and do not stutter. Although their data are inconsistent with participants who stutter in the present study, methodological differences between studies may account for inconsistencies. Two key factors may have contributed to divergent performance across studies: the auditory presentation of the phonemic cue, and lexical status of stimuli.

During silent phoneme monitoring tasks, participants in Sasisekaran et al. (2006) were provided auditory phonemic targets with an associated neutral vowel (i.e., “Please respond to the /g+ə/ in the naming of the following word.”) Results from previous implicit priming paradigms suggest that response times are faster as the segmental overlap between prime and target word increases (e.g., Burger & Wijnen, 1999; Meyer, 1991). Of the 14 target words used, two included neutral schwa vowels following the C1 consonant, and four included neutral vowels following the C3 consonant. Thus, shorter C1 and C3 responses for participants may have reflected, in part, the segmental overlap of the prime and target. This would be particularly beneficial for adults who stutter if they indeed retrieved a global syllable shape in which initial consonant and vowel were stored as an undivided unit. The present study, in contrast, provided auditory phonemic primes isolated from adjacent vowel. Provision of isolated, segmental cues may have increased demands on adults who stutter, particularly if, as presumed, they are uniquely compromised in their storage/access of segmental information.

Increased task complexity due to non-lexical status of stimuli provides an alternative account for the non-significant difference in reaction times between talker groups. Present findings are not consistent with previous studies by Sasisekaran and colleagues (Sasisekaran et al., 2006; Sasisekaran & de Nil, 2006), which found group differences in adults who do and do not stutter during silent phoneme monitoring tasks, However, task complexity differences due to nonlexical stimuli, if present, did not affect talker groups equally. As expected, poorer performance was observed in non-stuttering adults between studies when monitoring nonwords. Slower and less accurate response times for low frequency-nonword stimuli relative to real word stimuli would be expected in normally fluent adults (e.g., Balota, Law, & Zevin, 2000). In contrast, adults who stutter responded with relatively similar speed regardless of lexical status. In other words, adults who stutter seem to encode the nonword in the same manner as the real word suggesting that any benefit of segmentation that would be typical of real versus of non-word was not evident in their performance.

Differences based on the complexity of experimental task in fluent adults are consistent with disperate reaction time data reported in Wheeldon and Levelt (1995: translation task) and Wheeldon and Morgan (2002: paired word association task: see Figure 3). Non-lexical stimuli appeared to affect the overall response time of non-stuttering adults in the present study. Although exact reaction time latencies were not reported in Sasisekaran et al. (2006), visual inspection of data depicted in Figure 2 (p. 12) of their study illustrates non-stuttering adults monitored C1-C4 phonemes in real words within the approximate range of 750 to 1050 ms. Mean latencies over 1000 ms were observed for only one phoneme (i.e., C3). In the present study, when monitoring nonwords with initial stress, non-stuttering adults monitored C1-C4 phonemes with mean latencies between 891 and 1160 ms, with C2, C3, and C4 latencies greater than 1000 ms. As reported in Table 7 in the present study, the lower end of 95% confidence interval was above 997 ms for C2-C4. Thus, difficulty monitoring nonwords versus real words may have prolonged latencies following the initial consonant.

The more unexpected observation across studies was the comparable overall response latencies of adults who stutter when presented with real word and nonword stimuli. In Sasisekaran et al. (2006), C2-C4 monitoring latencies are greater than monitoring C1-C4 latencies greater than 1200 ms. In the present study, the upper bound of 95% confidence interval was less than 1275 ms for all but one phoneme (i.e., C4; see Table 7). Data across studies suggest that adults who stutter appear to perform equally as well processing nonword versus real word stimuli. This similarity can be discussed given the proposed structure of Levelt et al.'s (1999) model of speech production.

As described by Cholin et al. (2006), typical speech production benefits from access to the mental syllabary, a repository for high-frequency syllabic gestures that serves as a "hand-off" between phonological and phonetic levels of processing. In short, segmental information within high-frequency syllables activates their gestural score in the mental syllabary as soon as each syllable becomes available. Access to the mental syllabary theoretically results in less laborious, more 'automatic' speech production. In contrast, phonological code comprised of low-frequency and/or nonword syllables do not have access to the mental syllabary, and the segmental-metrical information must be fully computed from beginning-to-end in a left to right, incremental fashion before it becomes available to the articulatory system.

This "indirect route" of speech production requires more time to complete. Cholin et al. (2006) also state that this route can be employed to assemble high-frequency syllables in situations that require more on-line, conscious control of speech production by the speaker (e.g., lectures, self-corrections). Considering that adults who stutter have a lifelong history of stuttering, more conscious control of speech production may, in fact, be the norm. Thus, the differences in overall latencies between nonword production and real-word production in adults who stutter may be minimal.

5.4.2 Subvocal rehearsal

Previous researchers (Sasisekaran et al., 2006; Wheeldon & Morgan, 2002) acknowledge that silent phoneme monitoring tasks impose a demand on the phonological working memory system. Nonword training during the present study undoubtedly heightened these demands and threatened to compromise outcomes. Although reaction times assessed during silent phoneme monitoring tasks are thought to reflect the abstract, phonological code rather than the phonetic code (Levelt et al., 1999), the possibility exists that participants were instead monitoring the segmental information of phonetic code made available by sub-vocal rehearsal (Baddeley et al., 1975; see Baddeley, 2003, for review). Accounting for the influence of subvocal rehearsal is an important consideration when examining participants who stutter, as evidence mounts that phonological working memory abilities are weaker than typically fluent adults (e.g., Bajaj, 2007) and most vulnerable to disruption (e.g., Jones et al., 2012).

Baddeley et al. (1975) provide evidence to support that subvocal rehearsal is comprised, in part, by phonetic speech code. For example, Baddeley and Hitch (1974) found short-term memory span is linearly related and can be predicted from the number of words that can be read aloud in two seconds (Baddeley & Hitch, 1974) One approach to suppress the involvement of phonetic encoding is the articulatory suppression task. For example, Wheeldon and Levelt (1995) employed articulatory suppression (i.e., participant verbally counts out loud during monitoring task) to limit the amount of subvocal rehearsal possible during experimental trials. Wheeldon and Levelt found no significant difference in performance when silent phoneme monitoring tasks were conducted with and without articulatory suppression. These findings suggest that the information monitored was phonological rather than phonetic in nature and was not a product of subvocal rehearsal.

Another approach, perhaps more suitable to the already considerable demands of the nonword recall and silent phoneme monitoring required in the present study, is to examine whether monitoring of the consonant directly following the initial vowel is affected by its duration. Baddeley and Hitch (1974) found when additional factors such as word length (i.e., the number of syllables and phonemes in to-be-remembered words) were held constant, as in the present study, working memory continues to be affected by the duration of the vowel. These data suggest that phonetic properties of speech are retained during active use of subvocal rehearsal are provide a useful metric regarding the contribution of subvocal rehearsal during nonverbal response of participants.

Subsequent analysis in the present study did not reveal a significant difference in C2 latencies for either group when monitoring nonwords which contained tense versus lax vowel quality. These data support that the speech code being monitoring was the abstract phonological representation, rather than the phonetic subvocal representation. Again, these findings are consistent with those of Wheeldon and Levelt (1995), who found no significant change in silent phoneme monitoring latencies conducted with or without articulatory suppression. Thus, any differences (or lack thereof) observed can be more reliably attributed to differences in the phonological encoding abilities of participants in the present study.

In a recent study by Byrd, Vallely, Anderson, and Sussman (2012), adults who stutter exhibited a more pronounced effect of word length compared to typically fluent adults. Adults who stutter produced 7-syllable nonwords with significantly less accuracy (50%) than fluent adults. Adults who stutter also required significantly greater practice trials to produce target nonword accurately. These results are similar in nature to the word length effects reported by Baddeley et al. (1974), who found accuracy of immediate serial recall of five monosyllabic words (typically about 90%) drops approximately 50% when words in the list are 5-syllables in length (e.g., “university”). If subvocal rehearsal played a significant role in the performance of participants in Experiment 1, significantly poorer accuracy would have been observed during post-trial verbal response in adults who stutter. This was not the case.

Nevertheless, present data cannot unequivocally discount the possibility that participants employed some form of rehearsal during the inter-stimulus interval of the experimental task. Participants had minimal long-term linguistic, semantic, or phonological knowledge to aid accurate recall of nonwords. However, the lack of differences at C2 regardless of vowel quality, coupled with similar performance in verbal recall accuracy, provide greater confidence that subvocal rehearsal was not a significant contributor to the experimental results.

5.4.3 Training effects

An additional account for lack of overall reaction time differences between groups in the present study was the potential impact of increased training prior to experimental task. As reported by Smits-Bandstra (2010), participants who stutter often display longer reaction times compared to non-stuttering participants during simple response tasks (e.g., button-press). Smits-Bandstra further reported that these effects often diminished with sufficient practice. Similar to Byrd et al. (2012), adults who stutter in the present study were observed during subsequent analysis to require a significantly greater number of exposures to achieve accuracy criteria prior to experimental tasks (M = 21.86, SE = .51) than non-stuttering adults (M = 20.72, SE = .17; p = .018; minimum of 20 exposures). In contrast, participants in Sasisekaran et al. (2006) were required to name 13 of 14 pictures correctly, once, prior to silent phoneme monitoring tasks. If the amount of training was reduced and held constant for each participant, as in Sasisekaran et al., significant between-group differences may have emerged.

The number of pre-trial exposures was based on prior nonword learning data in typically fluent adults. For example, Storkel, Armbruster, and Hogan (2006) conducted a word learning paradigm in which 16 adults were exposed to CVC novel words associated with a referent within a narrative-context. Exposure varied from 1, 4, to 7 exposures. Accuracy of recall was measured by a subsequent referent-naming task. Even after seven prior exposures, and associated semantic knowledge, adults were only 40% to 60% accurate (i.e., produced all three phonemes correctly). Gupta (2003) employed a more rigorous nonword learning paradigm. Gupta exposed adults to bisyllabic nonwords with semantic referents 14 times prior to testing. Overall, adults achieved 97.90% accuracy during nonword recall probe.

Unlike these studies which employed a recognizable visual referent, the present study presented bisyllabic nonwords with neutral visual stimuli and only the location on screen to aid recall. It can be argued that the demands placed on short-term recall were greater in the present study, relative to previous nonword training tasks. Therefore, the minimum number of exposures (*n* = 20) was adjusted to include a greater number of exposures than Gupta (2003).

False negative error rates across Experiment 1 and 2 were commensurate with those reported by Sasisekaran et al. (2006). However, adults who stutter produced a greater amount of post-trial verbal errors in Experiment 2. Although the number of usable tokens was relatively comparable between groups in Experiment 1 and Experiment 2, it cannot be discounted that the increased demands of nonword learning may have influenced the speed of response between groups. In addition, greater repetition prior to testing may have also altered the strength of segmental activation for certain participants. Representation may have shifted from holistic to incremental more rapidly in some speakers, and perhaps even upgraded the target to "word-like" status. Given the variability of individual performance, increased training may have been more beneficial for a subgroup of adults who stutter, while others may have maintained weaker performance regardless of practice. Taken with data reported in Smits-Bandstra (2010), the influence of increased training in the present study is a notable factor worthy of consideration in future studies.

5.5 Theoretical implications

Of the four theories of stuttering considered as motivation for the present study, the holistic encoding theory (Byrd et al., 2007) and the Vmodel (Packman et al., 2007) best account for present data. This is due, in part, to the level of detail each provides regarding either segmental encoding (i.e., holistic encoding theory) or metrical properties (i.e., Vmodel) in relation to stuttered speech. The contribution of both metrical and segmental data in the present study provides greater specificity to each theory. By comparison, Wingate's (1988) 'fault-line' hypothesis and Howell's (2011) EXPLAN model are the least supported from present findings. This is due, in part, to the narrow ('fault-line') or broad (EXPLAN) predictions made within each theory.

5.5.1 Holistic encoding theory

Although Byrd et al. (2007) did not extend the holistic encoding theory into adults who stutter, present findings along with indirect support from previous studies (i.e., Sussman et al., 2010; Byrd et al., 2013) suggest that adults who stutter, on occasion, may "revert" to holistic planning, particularly in the presence of novel phonological stimuli. In the present study, typically fluent adults monitored C1 and C2 phonemes during stressed syllables in a remarkably invariant and incremental manner. In contrast, adults who stutter monitored C1 and C2 phonemes during stressed syllables with a relatively wide range of speed and accuracy. Previous studies of silent phoneme monitoring using real word stimuli with initial stress do not reflect the same pattern (Sasisekaran et al., 2006; Sasisekaran & Byrd, 2013). Findings from the present study suggest that when presented with novel word forms adults who stutter may activate the global, syllabic score rather than incremental assembly of segmental constituents.

Present data extend the holistic processing observed in children who stutter into adults who stutter in the presence of metrical stress. Adults who stutter certainly exhibited incremental encoding within most tokens in this study. It is possible that holistic processing occurs, perhaps as a default strategy, during conditions of increased demand. In the present study, participants who stutter were required to (a) learn novel stimuli, imposing greater demands on a arguably weaker phonological working memory, (b) complete silent phoneme monitoring tasks, which impose greater demands on an arguably weaker phonological encoding system, and (c) respond in a time-sensitive manner. Further evidence is required to assess under what conditions adults may (or may not) rely on holistic planning during speech production.

5.5.2 Vmodel

To review, Packman et al. (2007) consider moments of stuttering to occur due to the increased motoric effort required to produce variations in stress during connected speech. In the present study, data from non-verbal tasks revealed adults who stutter were more variable identifying segmental information within the initial, stressed syllable relative to typically fluent adults. Selection of the appropriate syllabic score from the mental syllabary (Levelt et al., 1999) is the locus of transmission of phonological to phonetic encoding. Thus, at least for some adults who stutter, activation of segments within the initial stressed syllable may be hindered, along with its availability in the articulatory buffer. Therefore, the delayed selection of gestural sores may also reflect variable or atypical phonological encoding in adults who stutter.

Variability in phonological planning serves as a valuable counterpart to the Vmodel put forth by Packman et al. (2007), who suggested the motoric demands variations in linguistic stress serve as a sufficient “trigger” mechanism for disfluent speech. Although variable motoric performance in adults who stutter has been reported extensively in recent literature (Namasivayam & van Lieshout, 2011; Smith et al., 2012), present data provide preliminary support that such variability may not be restricted to motor planning and/or execution. Instability observed within and between participants who stutter provides evidence for a fundamentally unstable phonological system, even in the absence of overt speech production, during stressed syllables. Thus, the hypotheses of the Vmodel can be broadened, as present data support the notion that more than one “trigger” can provoke a moment of stuttering.

In addition to delayed activation due to availability of segmental properties, Levelt (1989) suggested stressed and unstressed syllable forms are stored independently in the mental syllabary. If this is the case, reduction of the variability of stress patterns proposed by Packman et al. (2007) would also reduce the number of alternative, competing plans which differ only by stress demarcation within the syllabary. Fewer syllabic competitors would not only reduce the ambiguity encountered at the phonological level, but also ease the demands placed on the subsequent motoric system.

5.5.3 Fault-line

The present experimental data are consistent with Wingate’s (1988) proposition that stressed syllables present unique challenges to retrieval of segmental constituents. However, contrary to Wingate’s hypothesis, the stress-bearing vowel did not operate distinctly from the other phonemes within the syllable. All segments within the initial, stressed syllable were assigned in a variable manner, with C1 occasionally being identified more slowly or with equal latency as C2. Thus, although stress does appear to impact segmental encoding, data from the present study does not support that the breakdown does not occur exclusively between initial consonant and stress-bearing vowel.

As observed in Sussman et al. (2010), coarticulation of initial consonant+vowel segments within stuttered and fluent responses suggests that phonetic encoding and motor programming are not the locus of difficulty during stuttered speech production. Present data provide additional evidence to support this interpretation. In Experiment 1, variability between segments, particularly in the presence of metrical stress, may have resulted in more holistic encoding in adults who stutter. If phonological code is derived as a holistic syllable in the presence of metrical stress, minimal distinction of segmental content can be made at the phonological level. Together, data from Sussman et al. support the potential for atypical, holistic in encoding in adults who stutter, and data from the present study suggest this may be more apparent in the presence of initial stress.

Thus, while the prominence of initial stress in Wingate's (1988) theory is not off-target, the predictions of the fault-line theory need not be restricted to loci prior to stress-bearing vowels. Similar difficulty attributable to all segments within the stressed syllable would allow a broader range of disfluencies to occur on stressed syllables than simply sound repetitions or prolongations. In sum, if the predicted position of the 'fault-line' itself was modified to include all segments within stressed syllables, thus accounting for a broader range of disfluency types, the fault-line hypothesis becomes more ecologically valid.

5.5.4 EXPLAN

Findings are also somewhat compatible with Howell's (2011) EXPLAN model of stuttering in which he proposed a dissynchrony between levels of speech planning and execution. Present data indicate, at least for some adults who stutter, the presence of delayed or variable access to segmental information within the initial stressed syllable (i.e., C1-C2).

Speech onset latency data (Logan, 2003; Logan & Conture, 1997) suggest that individuals who stutter do not differ in the initiation of speech during fluent or stuttered utterances, regardless of phonological or syntactic composition. Variable or delayed access to the segmental information within a speech plan, coupled with invariant onset of execution, support the mechanism that triggers disfluency described within the EXPLAN model. Further, an inconsistent time course of phonological planning in adults who stutter provides additional rationale as to why the articulatory system cannot fully adapt to the periodic delays in speech planning.

However, present data do not necessarily support the EXPLAN as described by Howell (2010), as phonetic difficulty is described as the critical factor that delays speech planning. The present study indicates that difficulties occur even in the absence of overt speech production. As such, inclusion of a wider range of factors that disrupt the time course of speech planning is required within the EXPLAN model before present data can be considered support for this theoretical model of stuttered speech.

5.6 Clinical implications

The potential influence of metrical factors on phonological encoding abilities in adults who stutter provides additional support for the clinical intervention proposed by Packman et al. (2007). This treatment method incorporates a reduction in the range of stress variability during connected speech to facilitate fluent speech. Indeed, reduction of stress variability is a critical component across documented fluency enhancing techniques (e.g., rhythmic speech, prolonged speech). In addition to the reduced demands on motoric coordination, as described by Packman et al. (2007), reduced variability in stress may also facilitate selection of correct syllabic programs by reducing competition between stressed and unstressed phonetic plans, thought to be stored separately within the mental syllabary. Reduced ambiguity in speech plan activation would allow speech planning to occur in a timely manner prior to execution and perhaps produce the same reduction in disfluent speech.

The potential impact of specific fluency shaping techniques, such as easy onset may also be reflected in the present data. Increased pause time prior to speech production, often used to facilitate fluency in adults who stutter, may allow sufficient time to activate all segmental and metrical properties prior to production. Prolonged latencies of initial segments in the present study, extracted prior to fluent verbal responses, may capture this fluency facilitative technique in adult who stutter, many of whom have learned to manage the severity of their stuttering over time.

Present findings also support the proposed benefit of coupling traditional stuttering therapy with phonological awareness intervention for children who stutter (Byrd, Wolk, & Davis, 2007; Conture, Louko, & Edwards, 1993). However, in addition to bolstering knowledge of segmental properties, future clinical interventions may have reason to emphasize knowledge of metrical properties as well. For example, awareness of phonemes at or near the syllable boundary, along with metalinguistic games (i.e., syllable reversal) may provide diagnostic insight regarding the child’s abilities regarding of metrical aspects of speech. Future studies and clinical reports are required to investigate the validity of this suggestion, but present findings provide support for unique clinical consideration.

5.7 LIMITATIONS

The present study is not without limitations. Careful exclusionary and inclusionary criteria were followed prior to experimental testing. However, group differences were observed during certain subtests. In addition, as with most studies of low incidence disorders, the sample size could have been larger across both experiments. The potential impact of these variables will be discussed relative to present findings.

5.7.1 Pretest differences

Comparable performance on simple motor reaction time tasks indicate that data collected during non-verbal response times were not based on motor movement specific differences between talker groups. In addition, and similar to previous studies (e.g., Sasisekaran et al., 2006; Sasisekaran & de Nil, 2006), participants completed an auditory tone discrimination task. The purpose of this task was to ensure reaction time differences were not due to differences in auditory discrimination.

Non-significant differences in error rate and reaction time latencies confirmed that the participants' ability to monitor auditory information in general was not a confounding factor. In addition, tone series monitoring provided a baseline measurement of ability to monitor a string of auditory stimuli in the absence of lexical or phonological information. Increased latencies for silent phoneme monitoring tasks confirmed that latencies when monitoring CVCCVC stimuli during experimental tasks reflected time required to process phonological properties of stimuli.

In Experiment 1, groups did not significantly differ on eight of the nine tests of phonological skills. Adults who stutter performed significantly worse during onset segmentation in real words. These observed onset segmentation differences are not unlike those reported in Sasisekaran et al. (2006). In their study, participants who stutter performed significantly worse on both onset segmentation and rhyme judgment subtests.

First and foremost, it should be noted that underlying differences in phonological abilities in adults who stutter is not an unexpected finding. A considerable body of research supports subtle phonological differences are a common, if not distinctive, characteristic of children who stutter (for review, see Byrd, Wolk, & Davis, 2007) that often persists in adults who stutter (e.g., Bosshardt, 2002; Jones et al., 2012; Weber-Fox et al., 2004). Exclusion of these participants would reduce the accurate representation of the larger stuttering population.

In addition, although no standardized norms were available for the modified CTOPP subtest, both groups appeared to perform near ceiling (max score = 20) and differences between groups were within one point with limited variability observed in either group. While noteworthy, these differences do not suggest clinically impaired abilities within the adults who stutter, particularly when given the non-significant group differences in the eight additional tests of phonological abilities (e.g., nonword onset generation scores). Additionally, and perhaps the most critical point to consider - latency differences did not emerge when onset segmentation scores were included as a covariate. In Experiment 2, adults who stutter actually outperformed typically fluent adults in forward digit span. This difference was unexpected in light of previous studies which suggest phonological weaknesses in adults who stutter, particularly at the level of phonological working memory (see Bajaj, 2007, for review). Similar to Experiment 1, inclusion of digit span performance as a covariate did not alter experimental results.

Thus, data were not considered to be compromised by these differences in pre-test scores.

5.7.2 Sample size and effect size

Ideally, researchers would prefer to have a larger participant pool to allow for a more representative range of variability in adults who stutter. In the present study, limited statistical power due to modest sample size (N = 22) may have played a role in limiting the significance of some of the statistical comparisons.

To evaluate whether non-significant results were due to lack of statistical power, a post-hoc power analysis was conducted (G*Power ©; Buchner, Erdfelder, Faul, & Lang, 2012) with power ($1 - \beta$) set at 0.80 and $\alpha = .05$. Results revealed that samples sizes of N = 340 and N = 30 for Experiment 1 and 2, respectively, would be required in order for group differences to emerge. Post-hoc analysis further revealed that present sample sizes met sufficient criteria for significant group by position interactions to emerge (Experiment 1: power = .95; Experiment 2: power = .97). Thus, non-significant group differences cannot be attributed to limited sample size in Experiment 1. However, group differences may have emerged with a slightly larger sample size in Experiment 2.

One final consideration is that though we acknowledge a higher number of participants would further enhance the meaningfulness of our findings, we have included a significantly larger sample size of adults who stutter than previous studies which examined phonological encoding in adults who stutter (i.e., Burger & Wijnen, 1999; Wijnen & Boers, 1994). We also matched talker groups in latent phonological abilities to a markedly greater degree than previous studies prior to analysis.

Conclusion

In summary, segmental properties of phonological encoding appear to differ based on the metrical properties of speech. Data from Experiment 1 suggest that, in contrast to typically fluent adults and contrary to predictions, adults who stutter exhibit a *lack* of significant difference between C1 and C2 in the presence of initial stress. The results may be attributable to holistic representation of novel word stimuli in adults who stutter. Inconsistencies between studies may also reflect the advantage of increased practice trials provided in the present study. Preliminary data suggest that the predicted pattern may be more evident in phoneme monitoring latencies that were followed by stuttered productions of the target nonword.

Data from Experiment 2 yielded two main findings. First, as predicted, adults who stutter exhibited longer monitoring latencies for consonants that flank the syllable boundary (i.e., C2-C3). In contrast, typically fluent adults do not appear to exhibit longer monitoring latencies at the syllable boundary. Adults who stutter appear to require more time to access phonemes at the syllable boundary above and beyond the processing time allowed when encoding the initial syllable.

Second, while false positive responses did not differ between groups, adults who stutter exhibited a significantly greater number of phonemic and stress-assignment errors when producing words with non-initial stress. Increased stress-assignment errors may reflect compromised retrieval or storage of metrical information, or perhaps conscious strategies by speaker to facilitate fluent and accurate recall of nonword targets with non-initial stress patterns.

Findings from Experiment 2 suggest that assignment of syllable boundary, in the absence of initial stress, significantly delays assignment of phonemes in the second syllable. Delays in syllable boundary assignment are in accordance with the disfluency patterns Natke et al. (2004) observed in the conversational speech of persons who stutter. Assignment of metrical stress on the initial syllable results in similarly delayed availability of all phonemes within the syllable prior to fluent verbal responses. Inconsistent availability of all phonemes within the initial stressed syllable sets the stage for delayed assignment of segments at syllable-initial, syllable-medial, and syllable-final positions. By this account, the breadth of disfluency types that could occur on stressed syllables expands beyond those reported in previous studies.

Although present data are preliminary and additional investigation is warranted, findings suggest the phonological encoding difficulties previously identified in adults who stutter are not limited to segmental properties. Rather, phonological encoding difficulties can be extended to include both segmental and metrical properties. Together, the relationship between metrical and segmental encoding abilities in adults who stutter may uniquely compromise the ability to establish and/or maintain fluent speech.

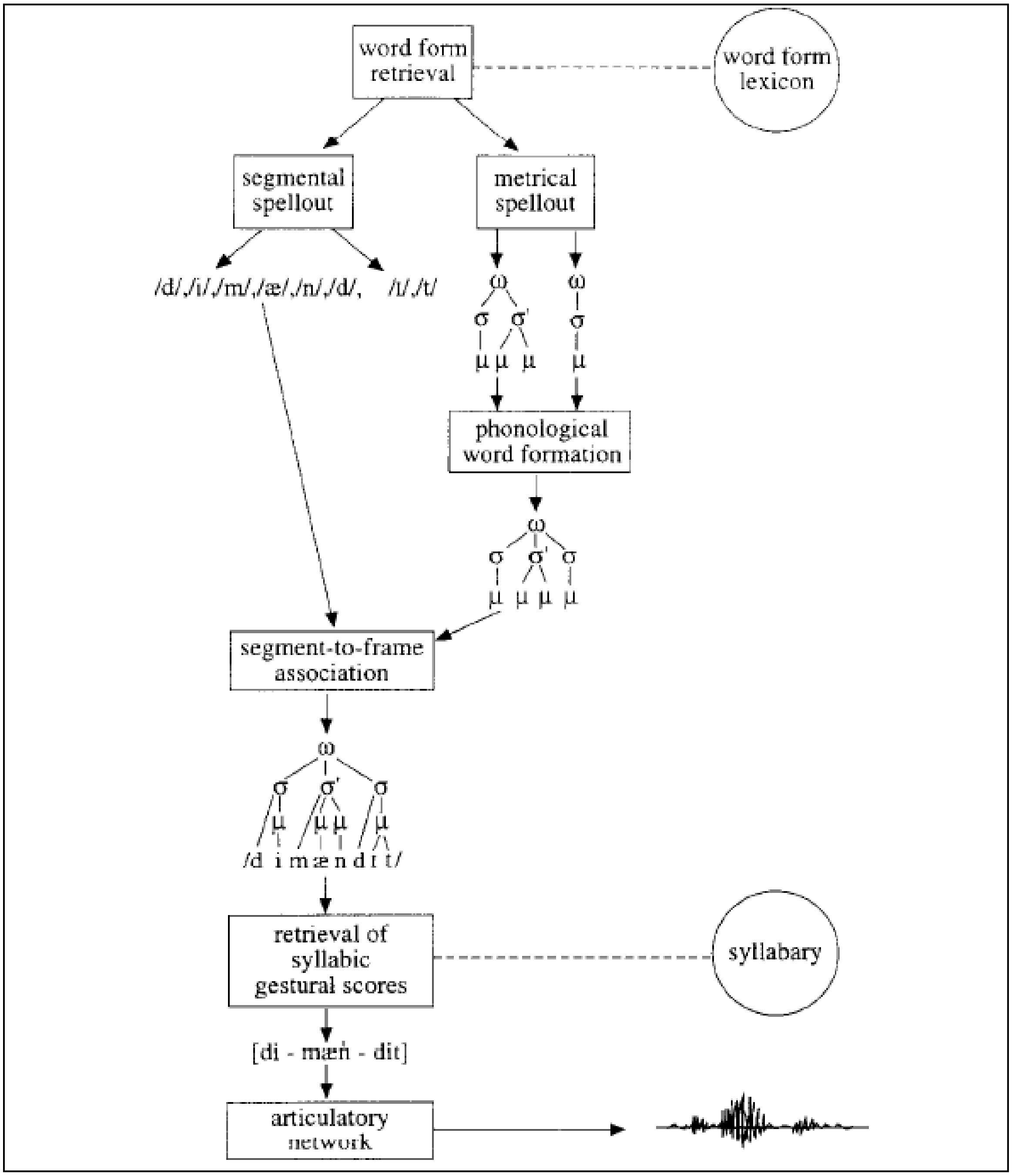

Figure 1. Levelt et al.'s (1999) model of phonological encoding (from Levelt & Wheeldon, 1994).

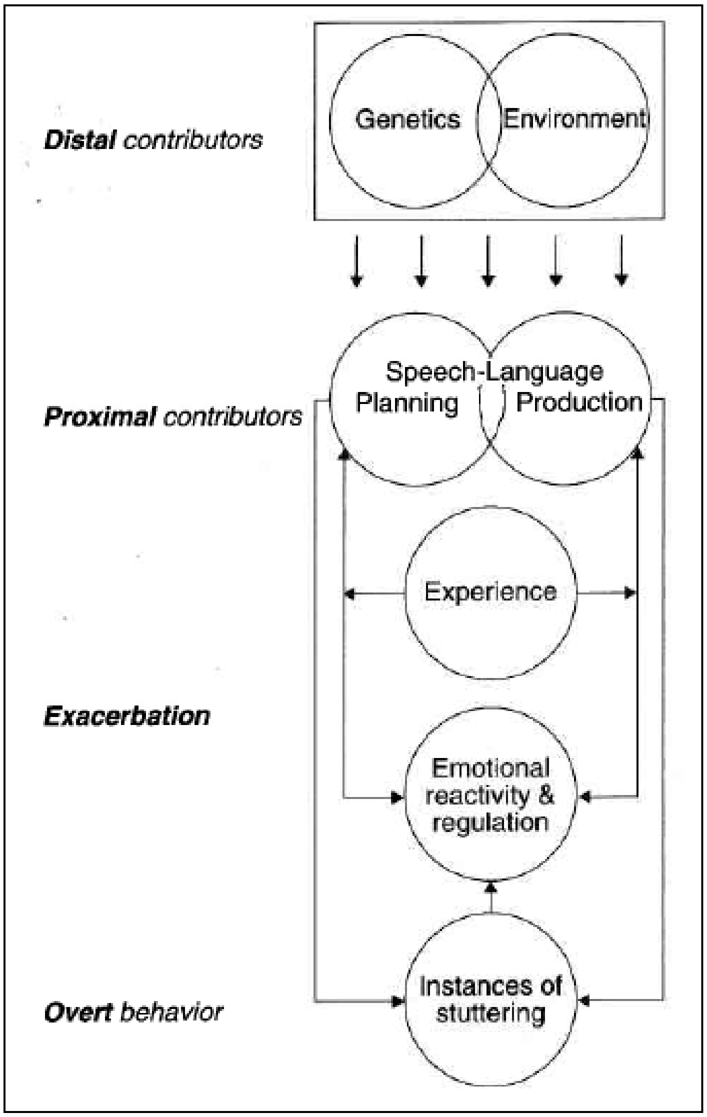

Figure 2. Communicative-Emotional Model of stuttering (Conture et al., 2006).

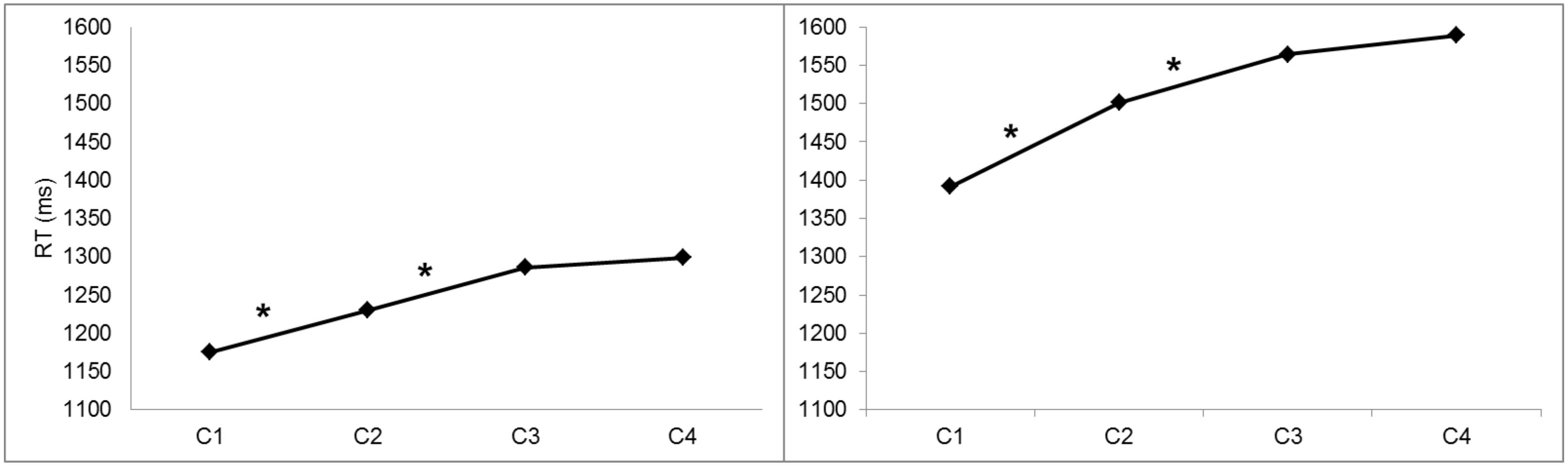

Figure 3. Silent phoneme monitoring latencies of CVCCVC stimuli in two studies with typically fluent adults (left: Wheeldon & Levelt, 1995; right: Wheeldon & Morgan, 2002). * $p < .05$.

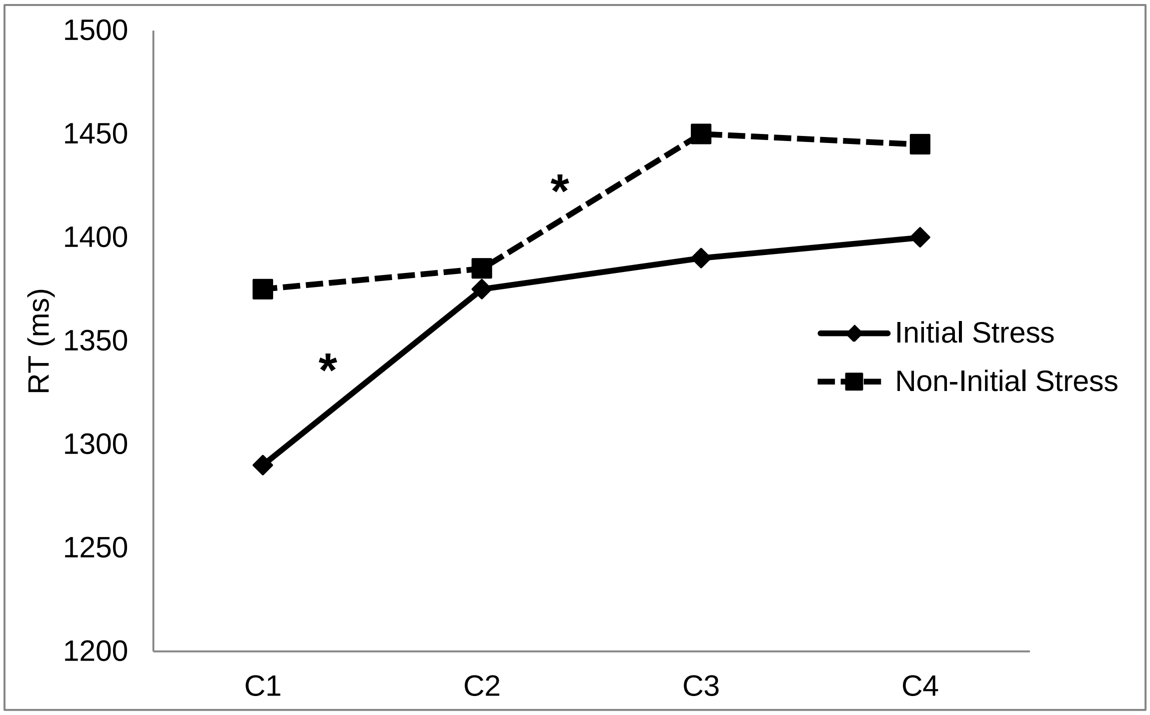

Figure 4. Silent phoneme monitoring latencies for CVCCVC stimuli with initial and non-initial stress in typically fluent adults (Schiller, 2005). * $p < .05$.

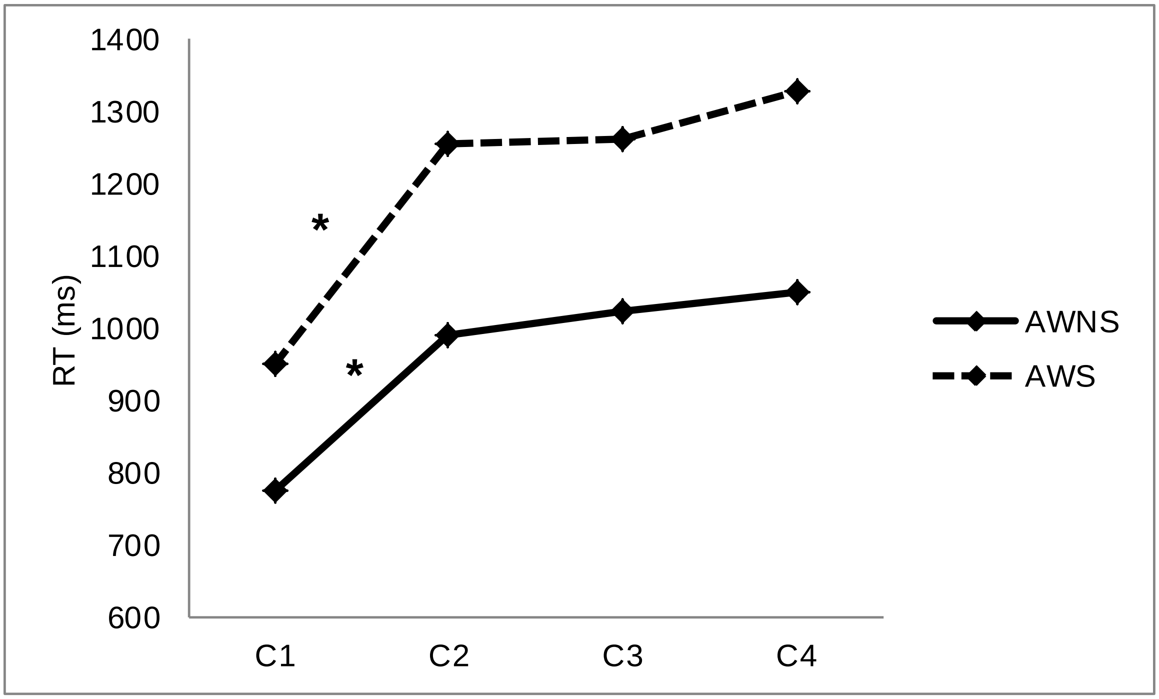

Figure 5. Silent phoneme monitoring latencies for CVCCVC stimuli in adults who do not stutter (AWNS) and adults who stutter (AWS; Sasisekaran et al., 2006). * *p* < .05.

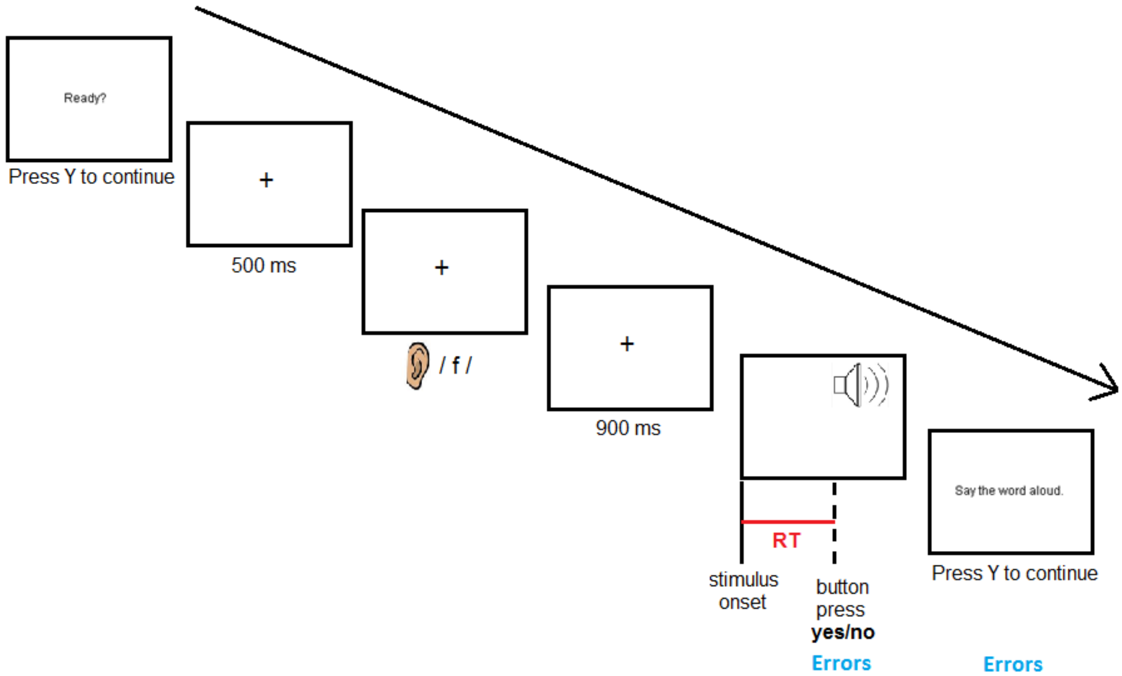

Figure 6. Accuracy and reaction time (RT) latency measurements during adapted silent phoneme monitoring task. Errors include false positive responses, phonemic error during verbal response, and stress-based errors during verbal response.

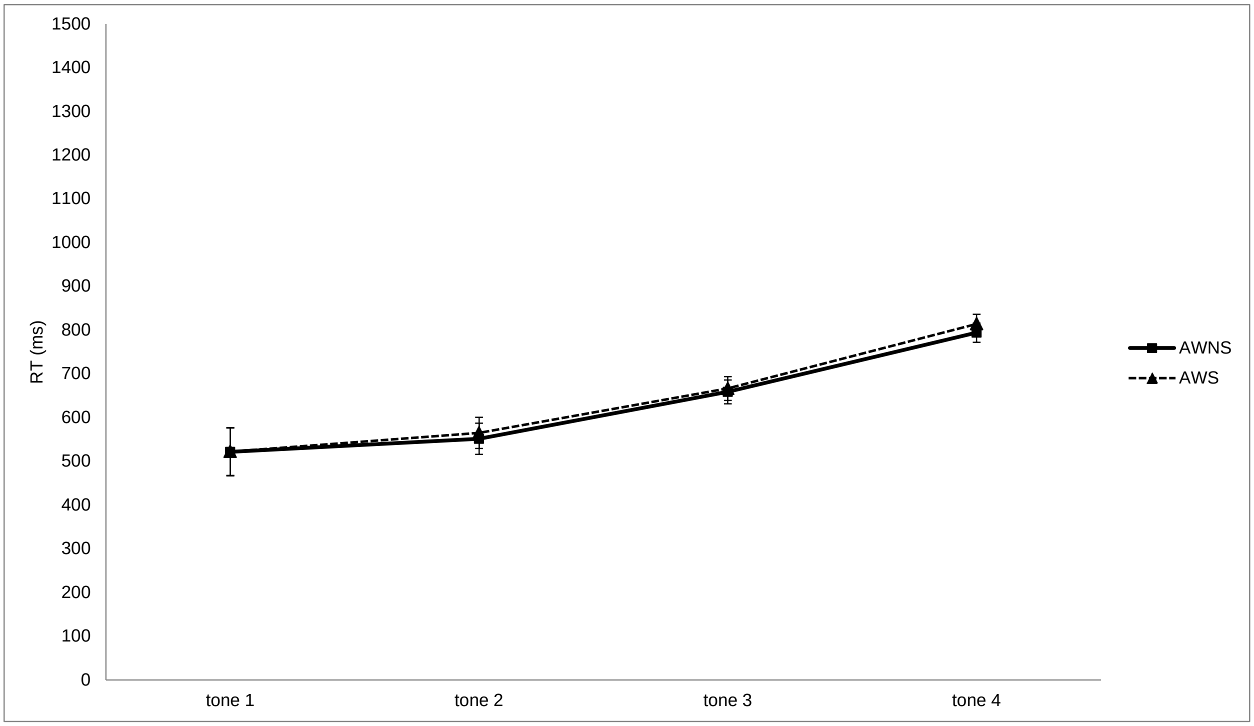

Figure 7. Reaction time (RT) latencies for adults who do not stutter (AWNS) and adults who stutter (AWS) identifying one high tone (1 kHz) in a four-tone auditory sequence (.5 kHz). Error bars represent standard error of the mean.

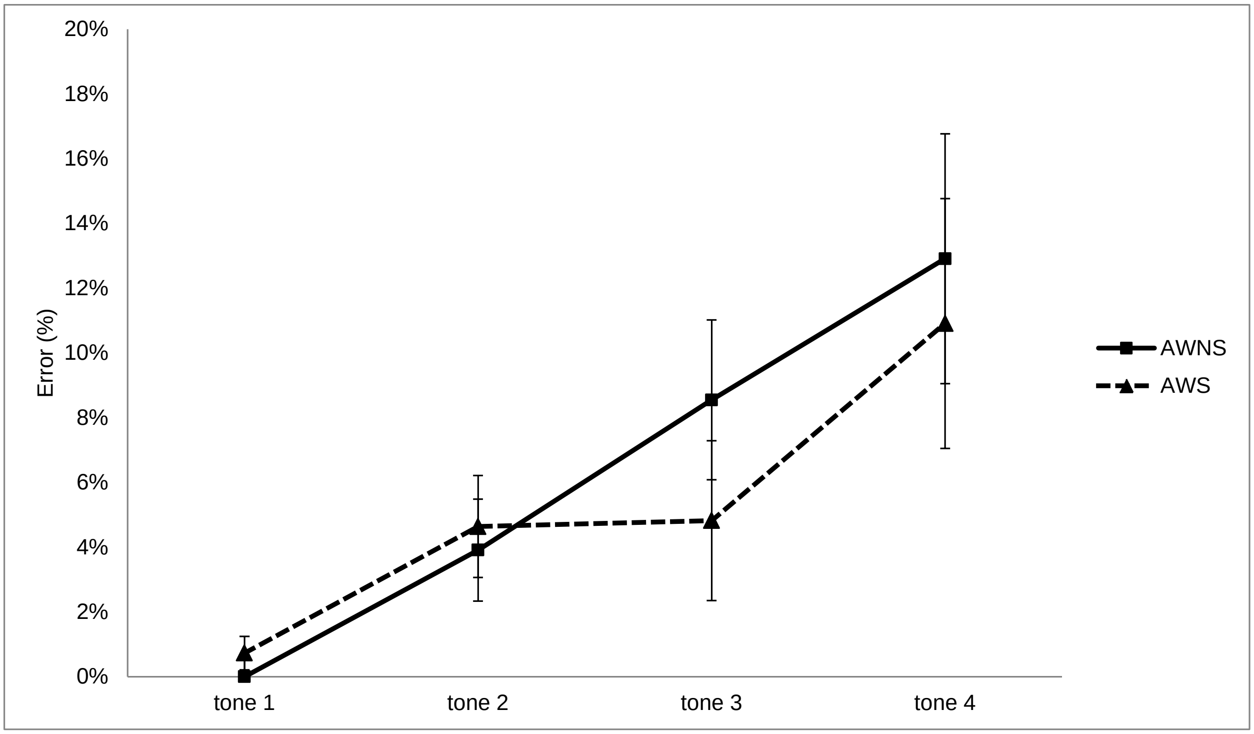

Figure 8. Percent of false negative errors for adults who do not stutter (AWNS) and adults who stutter (AWS) identifying one high tone (1 kHz) in a four-tone auditory sequence (.5 kHz). Error bars represent standard error of the mean.

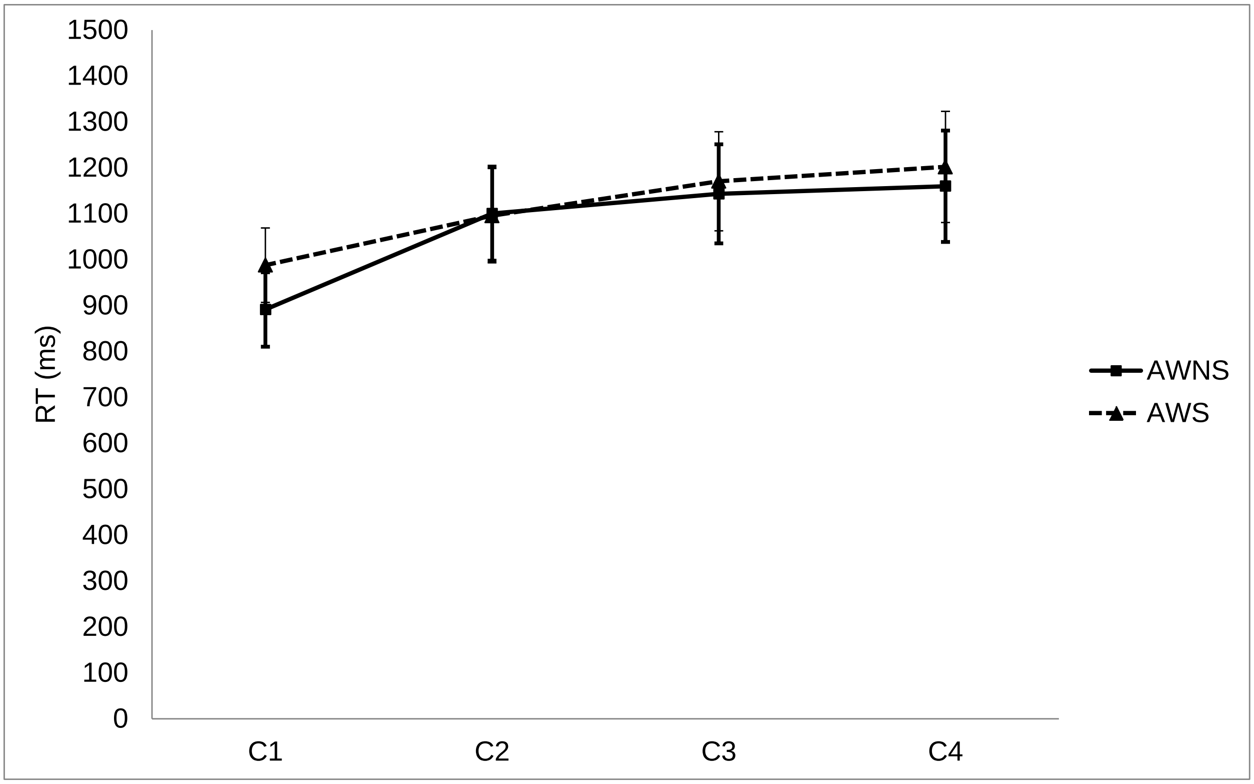

Figure 9. Mean reaction time latencies for adults who do not stutter (AWNS) and adults who stutter (AWS) silently monitoring phoneme for CVCCVC nonwords with initial syllabic stress. Error bars represent standard error of the mean.

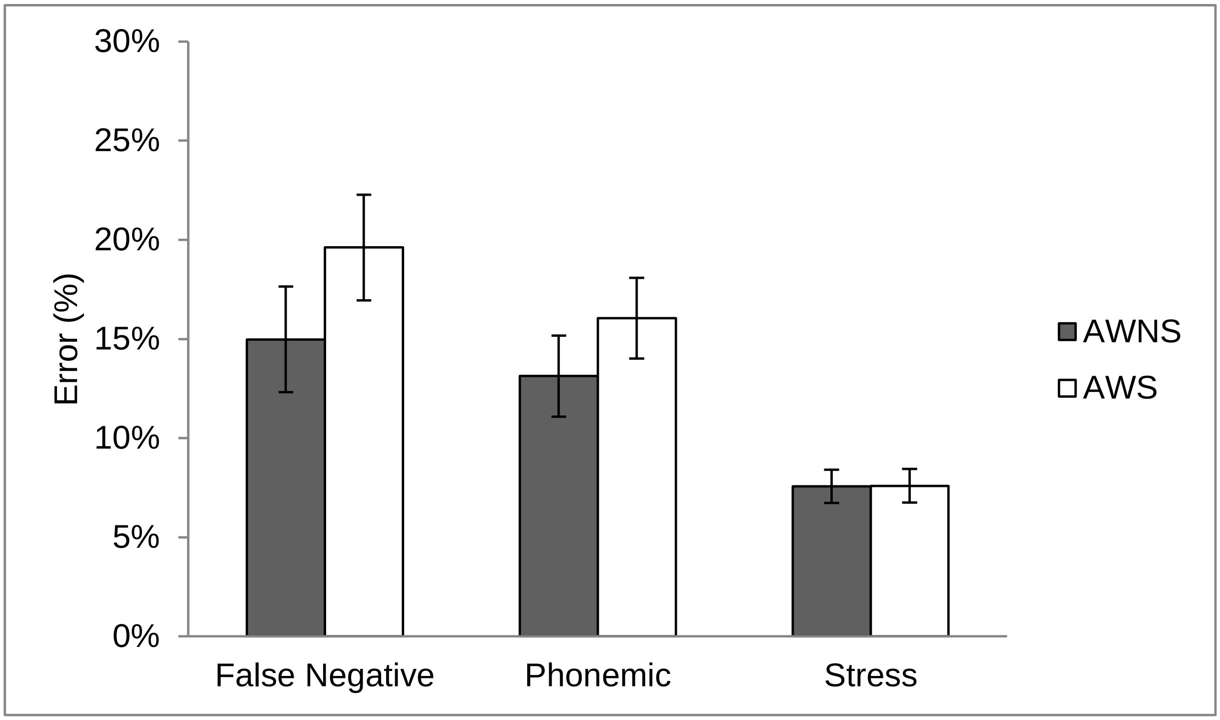

Figure 10. Mean percent errors of false negative errors, phonemic errors, and stress errors by adults who do not stutter (AWNS) and adult who stutter (AWS) during silent phoneme monitoring task of CVCCVC nonwords with initial syllabic stress. Error bars represent standard error of the mean.

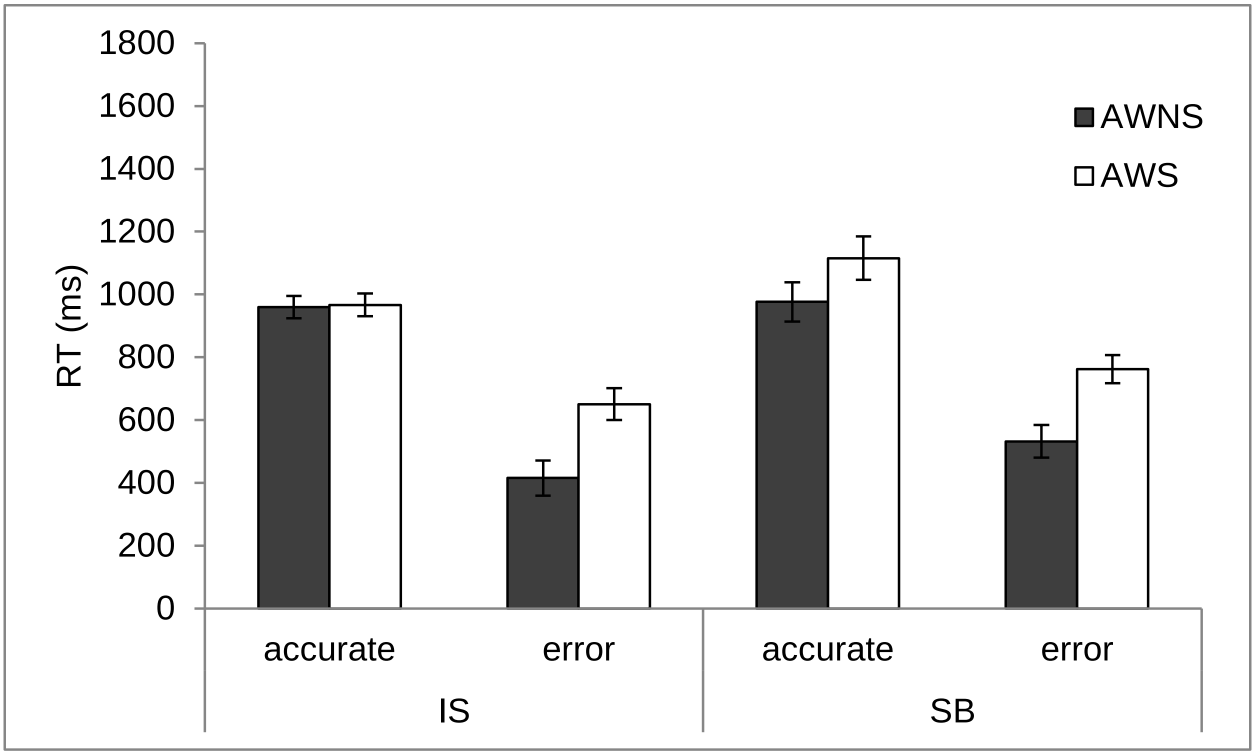

Figure 11. Manual reaction time (RT) for adults who do not stutter (AWNS) and adults who stutter (AWS) during accurate response and inaccurate response when silently monitoring nonwords with initial syllable stress (left) and without initial stress (right). Error bars represent standard error of the mean.

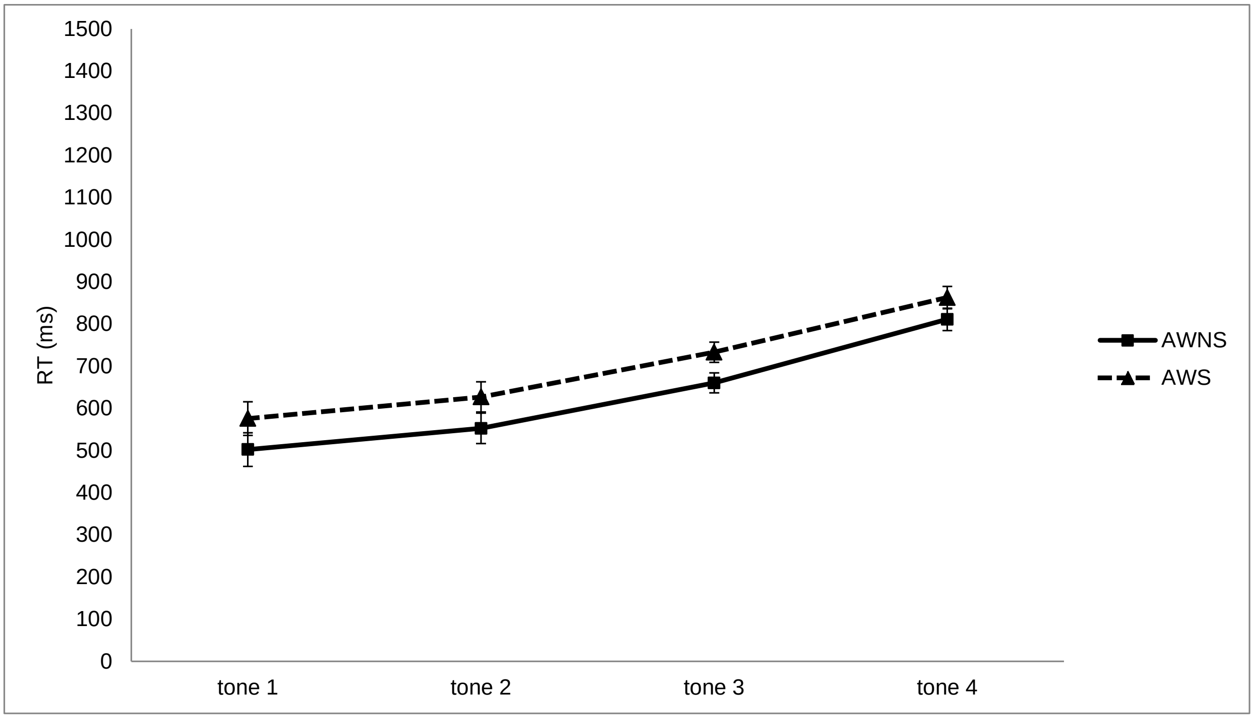

Figure 12. Reaction time (RT) latencies for adults who do not stutter (AWNS) and adults who stutter (AWS) identifying one high tone (1 kHz) in a four-tone auditory sequence (.5 kHz). Error bars represent standard error of the mean.

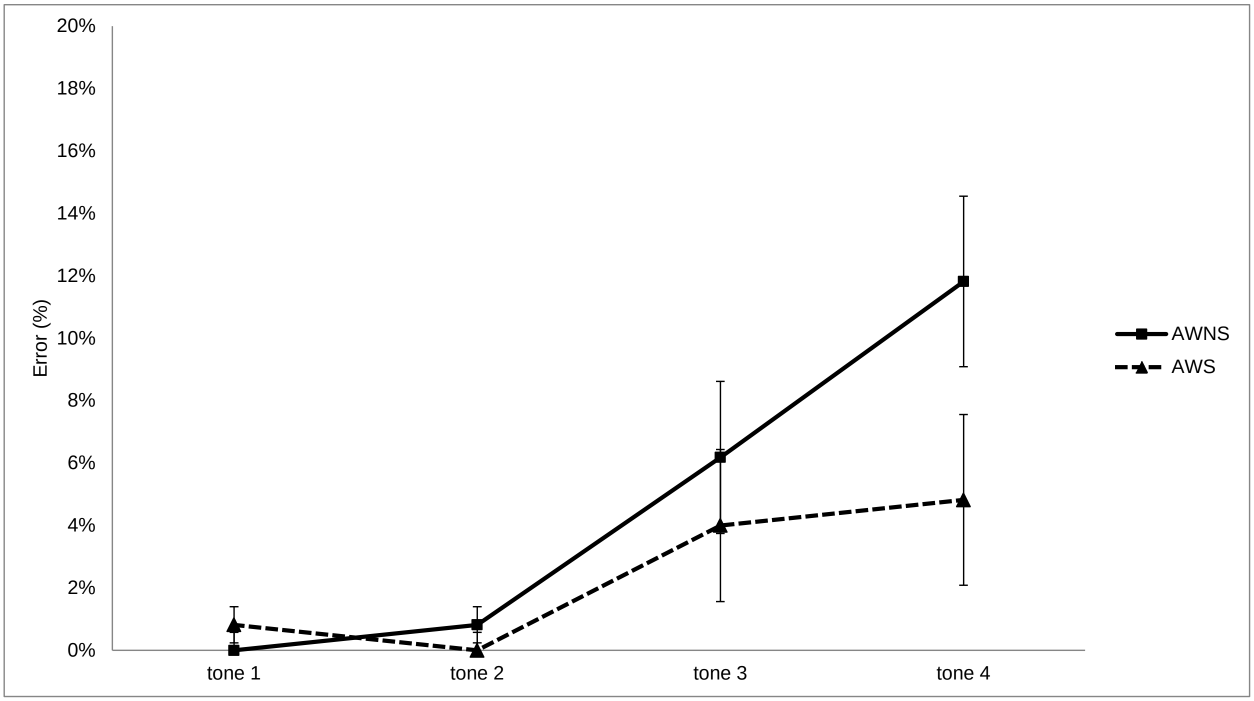

Figure 13. Percent of false negative errors for adults who do not stutter (AWNS) and adults who stutter (AWS) identifying one high tone (1 kHz) in a four-tone auditory sequence (.5 kHz). Error bars represent standard error of the mean.

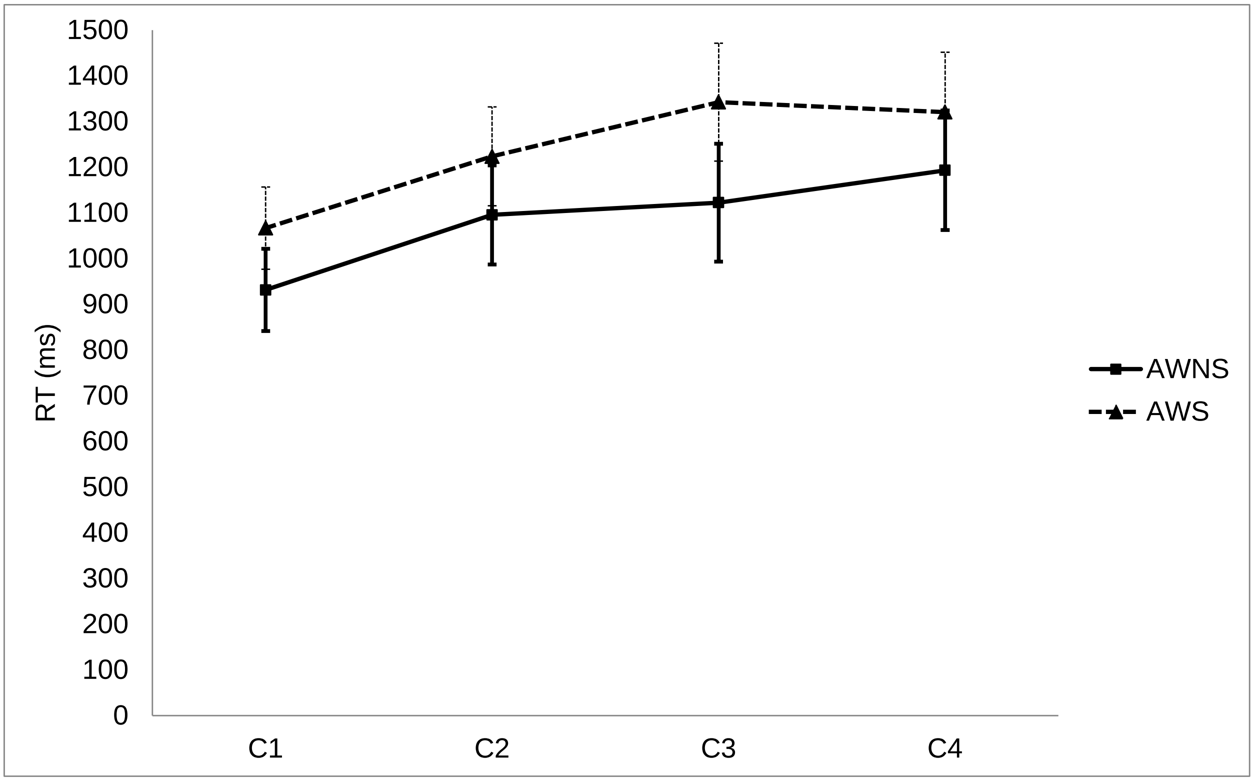

Figure 14. Mean reaction time latencies for adults who do not stutter (AWNS) and adults who stutter (AWS) silently monitoring phoneme for CVCCVC nonwords with syllable boundary as the first metrical property. Error bars represent standard error of the mean.

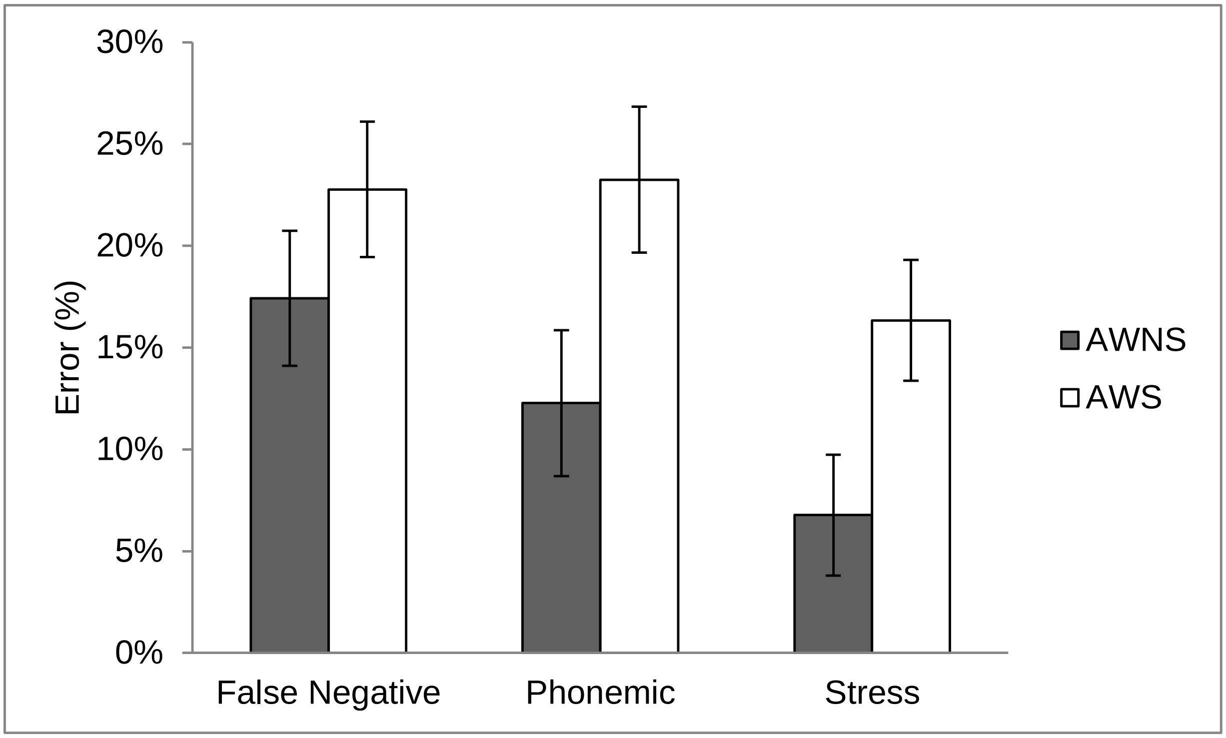

Figure 15. Mean percent errors of false negative errors, phonemic error, and stress errors by adults who do not stutter (AWNS) and adults who stutter (AWS) during silent phoneme monitoring task of CVCCVC nonwords without initial syllabic stress. Error bars represent standard error of the mean.

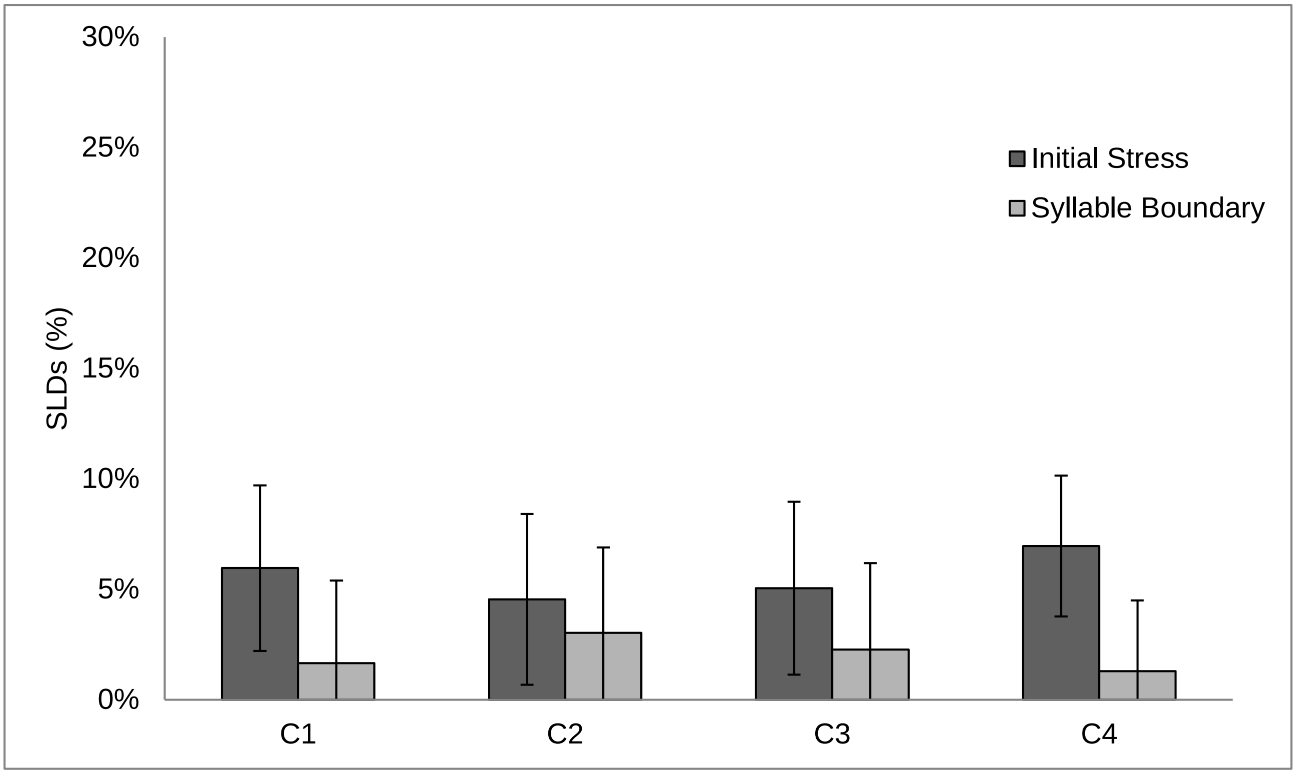

Figure 16. Mean stuttering-like disfluencies (SLDs) produced by adults who stutter after silent phoneme monitoring task of CVCCVC nonwords with initial stress or syllable boundary as the first-encountered metrical property. Error bars represent standard error of the mean.

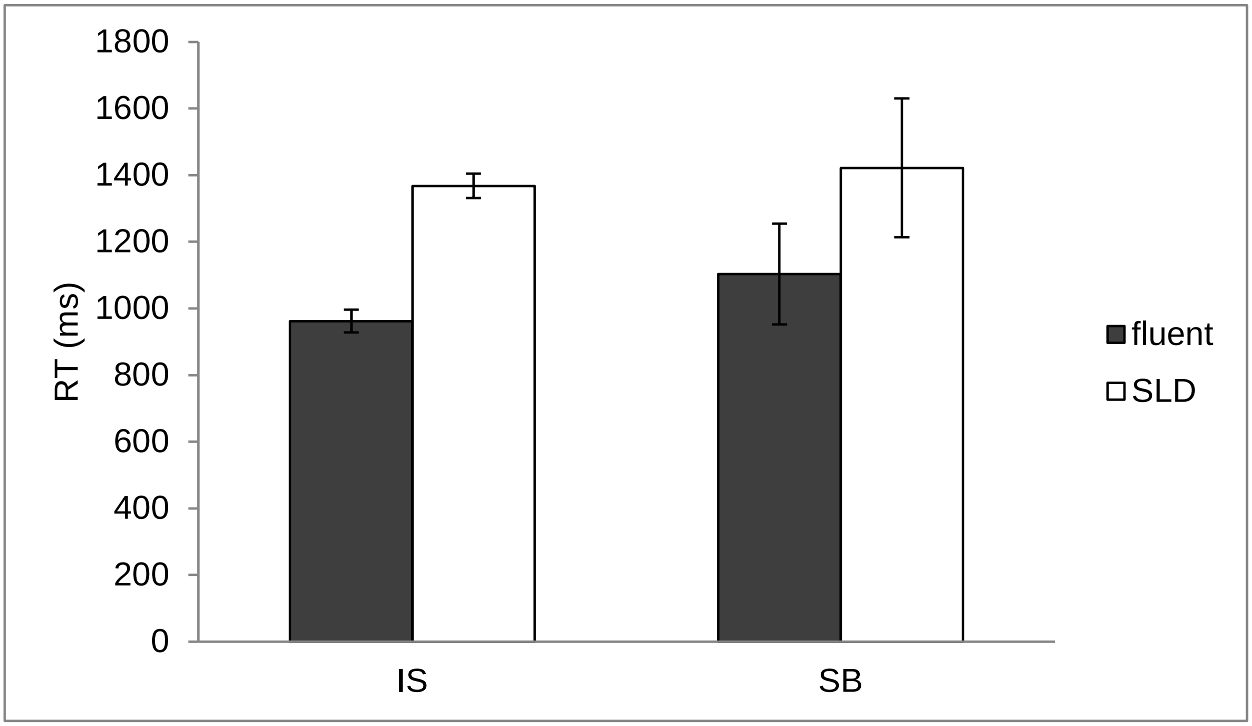

Figure 17. Manual reaction time (RT) for adults who do and do not stutter (AWS, AWNS) during fluent responses and responses produced with a stuttering-like disfluency (SLD) after monitoring bisyllabic nonwords with initial stress (IS) or initial syllable boundary (SB). Error bars represent standard error of the mean.

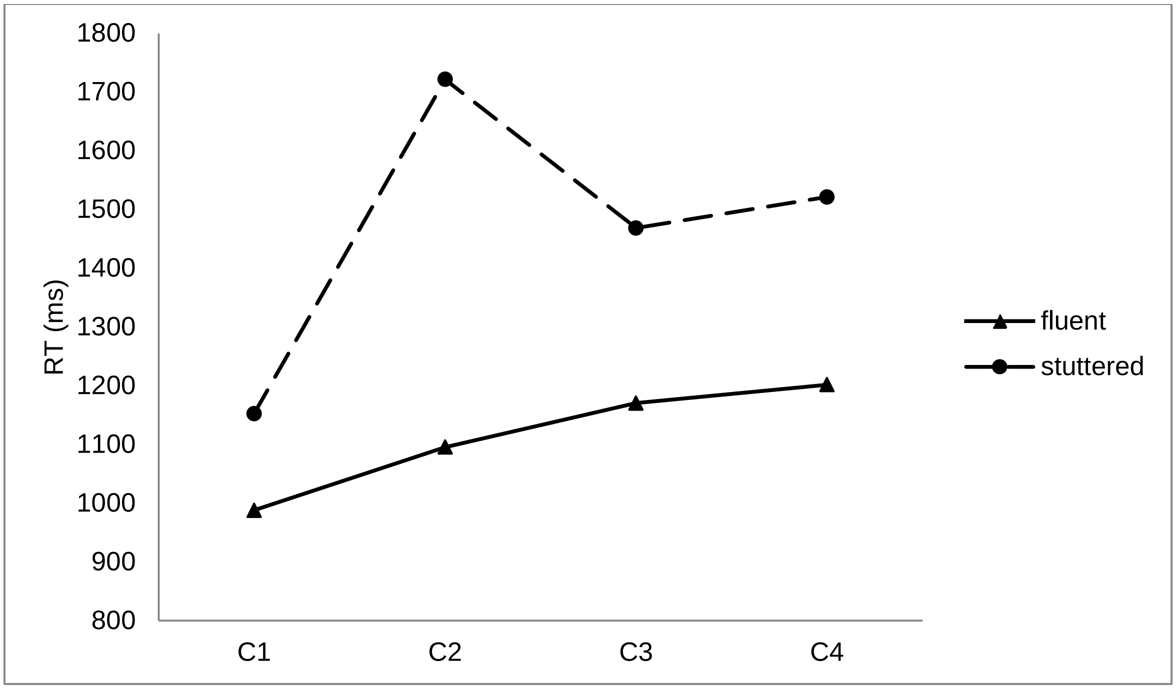

Figure 18. Reaction time (RT) latencies of silent phoneme monitoring task for adults who stutter prior to fluent and stuttered verbal responses.

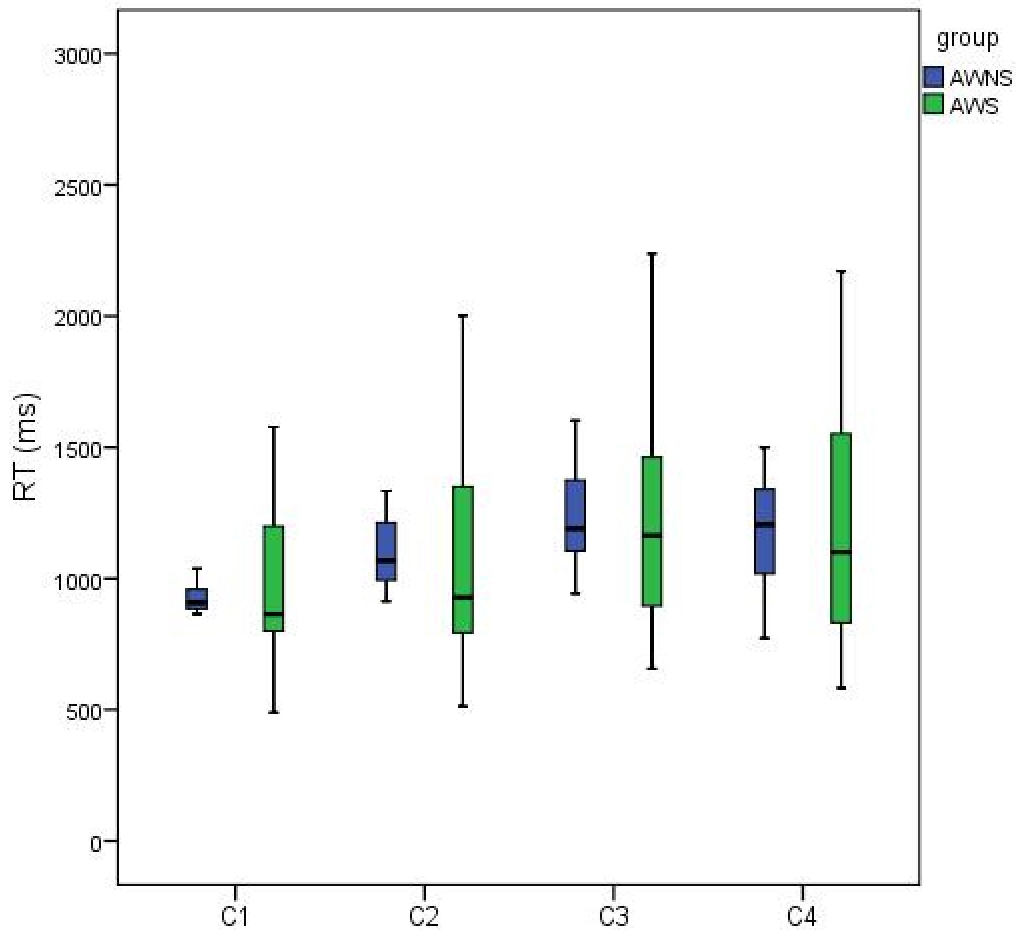

Figure 19. Overall mean silent phoneme monitoring latencies for adults who do and do not stutter (AWS and AWNS) at each consonant position in $C_1VC_2C_3VC$ nonword stimuli with initial stress.

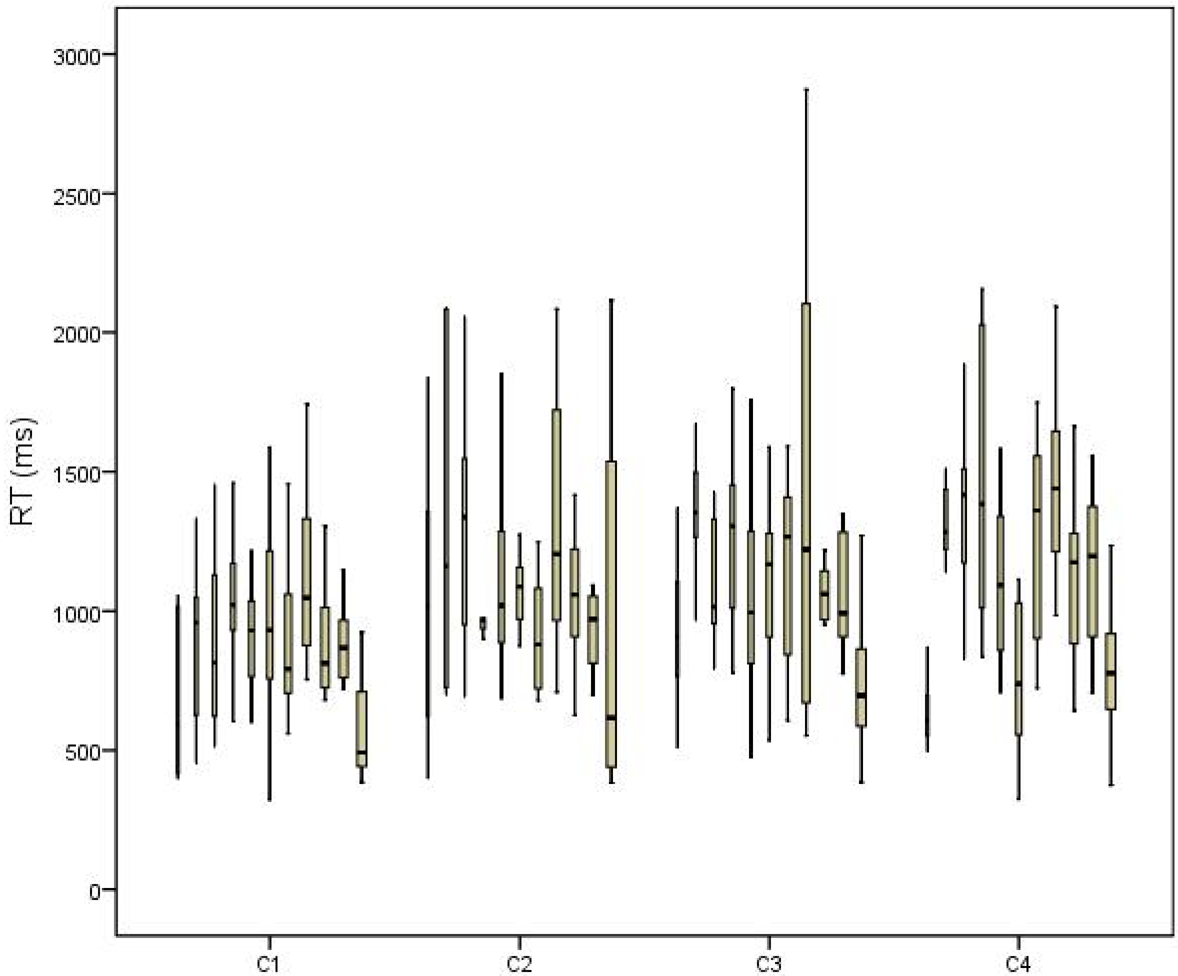

Figure 20. Distribution of silent phoneme monitoring latencies for individual participants who do not stutter at each consonant position in $C_1VC_2C_3VC_4$ nonword stimuli with initial stress.

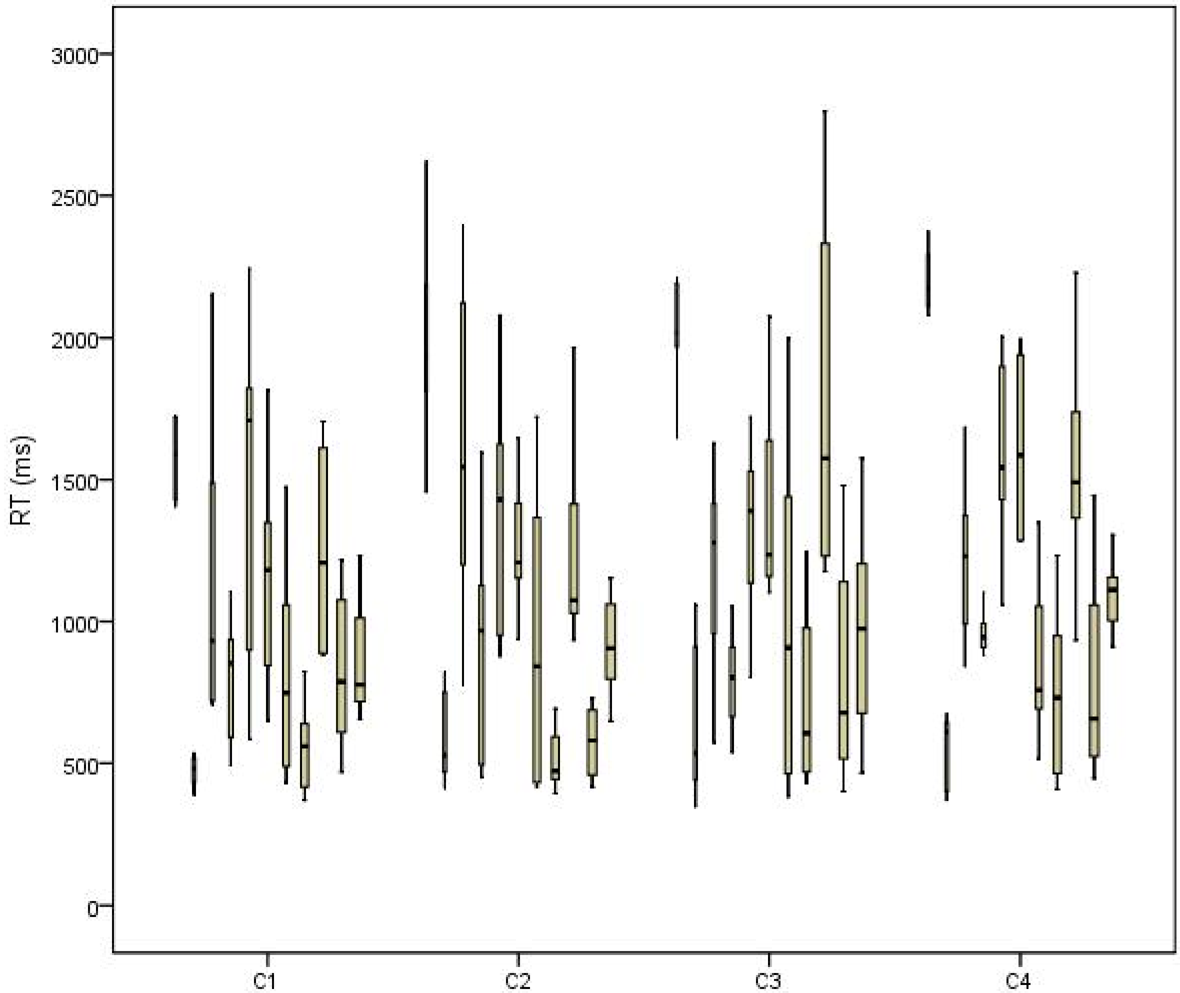

Figure 21. Distribution of silent phoneme monitoring latencies for individual participants who stutter at each consonant position in $C_1VC_2C_3VC_4$ nonword stimuli with initial stress.

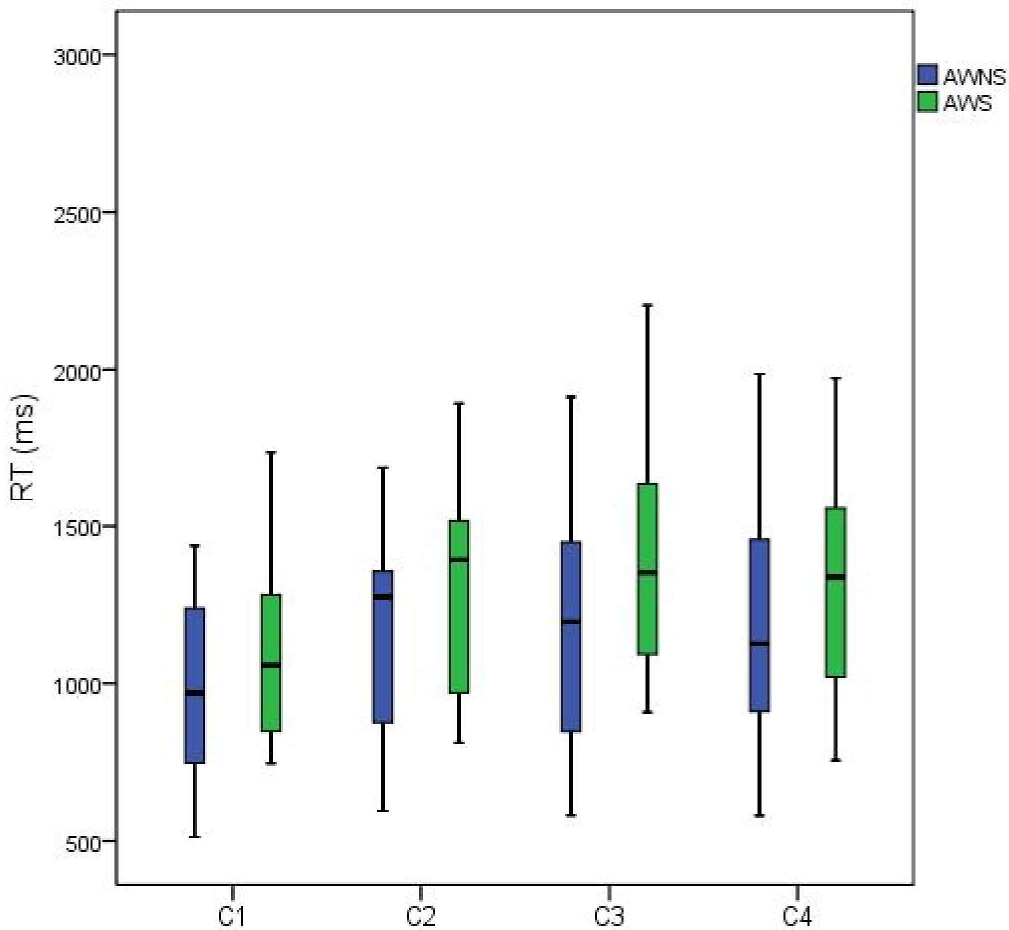

Figure 22. Mean reaction time (RT) latencies for adults who do and do not stutter (AWS and AWNS) monitoring CVCCVC nonwords with non-initial stress. C1: <u>C</u>VCCVC C2: CV<u>C</u>CVC C3: CVC<u>C</u>VC C4: CVCCV<u>C</u>.

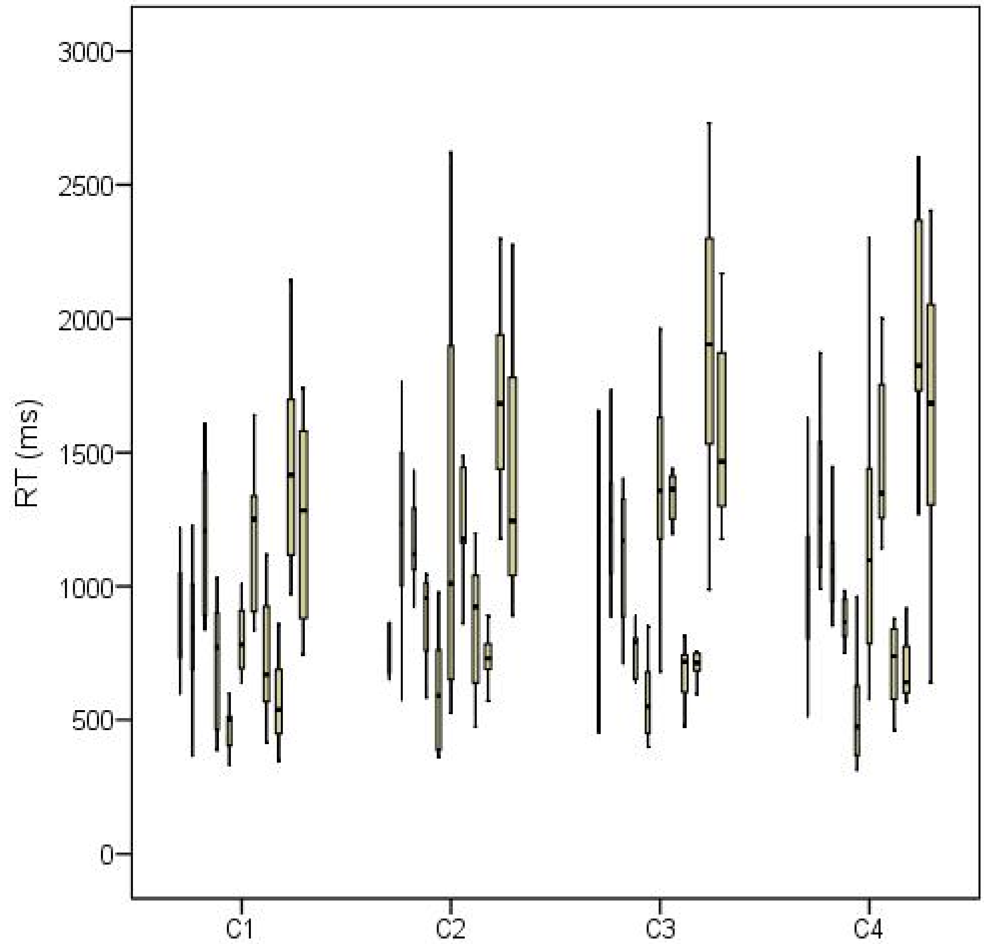

Figure 23. Distribution of silent phoneme monitoring latencies for individual participants who do not stutter at each consonant position in $C_1VC_2C_3VC_4$ nonword stimuli without initial stress.

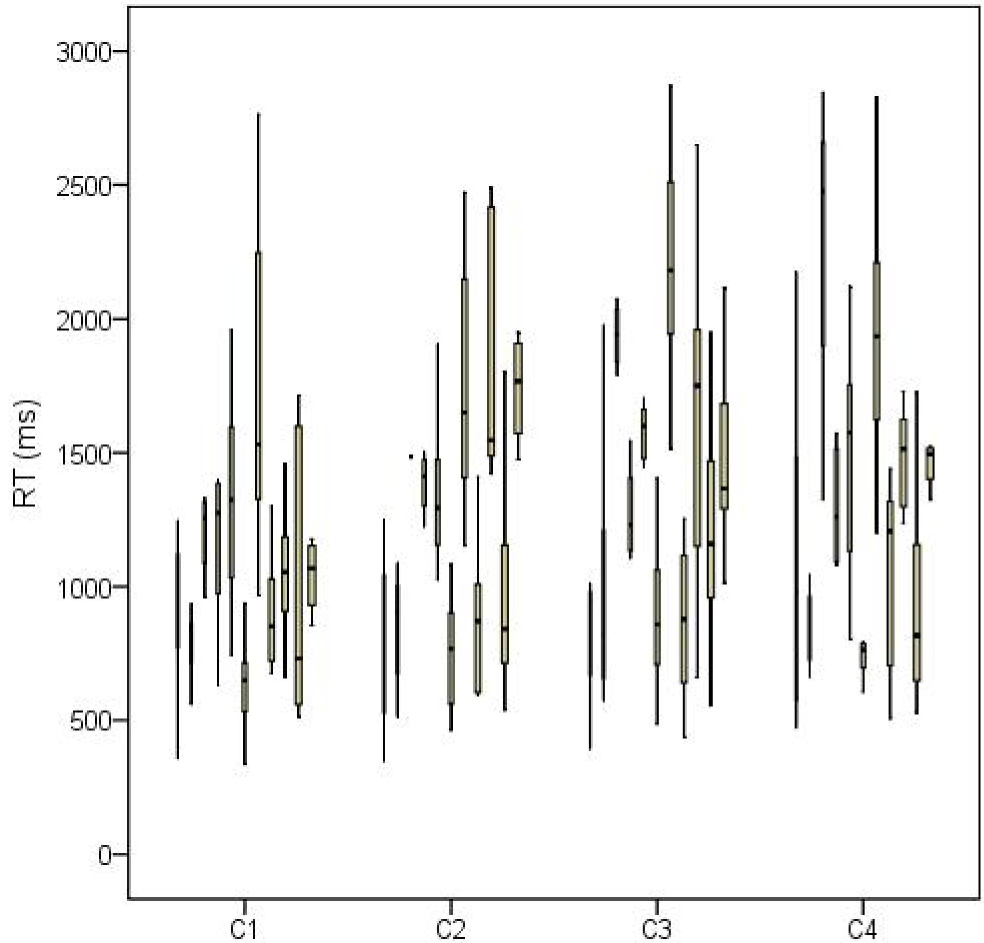

Figure 24. Distribution of silent phoneme monitoring latencies for individual participants who stutter at each consonant position in $C_1VC_2C_3VC_4$ nonword stimuli without initial stress.

Table 1

Participant characteristics for adults who do not stutter – Experiment 1.

			Conversational Sample			Reading Sample						
P	Gender	Age	%SLD	Severity Score	Stuttering Severity	%SLD	Severity Score	Stuttering Severity	Overall %SLD	Overall Severity	Previous Dx	Self-ID
1	M	19	0.33	1	N/A	0.00	1	N/A	0.17	1.00	N	N
2	M	20	2.33	1	N/A	0.30	1	N/A	1.32	1.00	N	N
3	M	19	1.00	1	N/A	1.18	1	N/A	1.09	1.00	N	N
4	F	23	0.00	1	N/A	0.30	1	N/A	0.15	1.00	N	N
5	M	23	1.00	1	N/A	0.89	1	N/A	0.95	1.00	N	N
6	M	26	0.33	1	N/A	0.59	1	N/A	0.46	1.00	N	N
7	M	21	0.00	1	N/A	0.30	1	N/A	0.15	1.00	N	N
8	M	19	0.67	1	N/A	0.60	1	N/A	0.64	1.00	N	N
9	F	18	0.67	1	N/A	0.59	1	N/A	0.63	1.00	N	N
10	F	18	2.00	1	N/A	0.60	1	N/A	1.30	1.00	N	N
11	F	18	1.50	1	N/A	0.30	1	N/A	0.90	1.00	N	N
M		20.36	0.89	1.00	N/A	0.51	1.00	N/A	0.71	1.00	Y=0	Y=0
SD		2.50	0.74	0.00	N/A	0.31	0.00	N/A	0.42	0.00	N=11	N=11
Min		18	0.00	1	N/A	0.00	1	N/A	0.15	1		
Max		26	2.33	1	N/A	1.18	1	N/A	1.32	1		

Note: P: participant; %SLD: percentage of stuttering-like disfluencies per sample; M: male; F: female; Age: age in years; Severity Score: score on scale of stuttering severity (O'Brian et al., 2004); Previous Dx: previous diagnosis of stuttering; Self-ID: participant self-identification as an adult who stutters; Y: yes, N: no; mod: moderate; mild-mod: mild to moderate; sev: severe; ex sev: extremely severe; N/A: not applicable.

Table 2

Participant characteristics for adults who stutter – Experiment 1.

			Conversational Sample			Reading Sample						
P	Gender	Age	%SLD	Severity Score	Stuttering Severity	%SLD	Severity Score	Stuttering Severity	Overall %SLD	Overall Severity	Previous Dx	Self-ID
12	M	19	13.33	5	mod	7.37	5	mod	10.35	5.00	N	Y
13	M	22	8.67	4	mild-mod	9.50	7	sev	9.09	5.50	Y	Y
14	M	20	4.00	4	mild-mod	23.08	7	sev	13.54	5.50	Y	Y
15	M	20	13.67	6	mod-sev	20.18	7	sev	16.93	6.50	Y	Y
16	F	18	0.33	2	very mild	3.25	2	very mild	1.06	2.00	N	Y
17	F	19	4.00	3	mild	3.53	3	mild	3.77	3.00	N	Y
18	M	19	7.67	4	mild-mod	4.14	3	mild	5.91	3.50	Y	Y
19	F	24	3.33	3	mild	0.00	1	none	1.67	2.00	N	Y
20	M	41	14.00	8	very sev	6.80	7	sev	10.40	7.50	Y	Y
21	M	22	4.00	3	mild	0.60	2	very mild	2.30	2.50	N	Y
22	F	21	1.75	1	none	2.00	2	very mild	1.88	1.50	Y	Y
M		22.27	6.80	3.91	mild-mod	7.31	4.18	mild-mod	6.99	4.05	Y=6	Y=11
SD		6.15	4.76	1.83	N/A	7.30	2.33	N/A	5.15	1.95	N=5	N=0
Min		18	0.00	1	none	0.00	1	none	0.15	1.5		
Max		26	2.33	8	very sev	1.18	7	sev	1.32	7.5		

Note: P: participant; %SLD: percentage of stuttering-like disfluencies per sample; M: male; F: female; Age: age in years; Severity Score: score on scale of stuttering severity (O'Brian et al., 2004); Previous Dx: previous diagnosis of stuttering; Self-ID: participant self-identification as an adult who stutters; Y: yes, N: no; mod: moderate; mild-mod: mild to moderate; sev: severe; ex sev: extremely severe; N/A: not applicable.

Table 3

Lexical, linguistic, and phonological properties of nonword stimuli.

Factor	Mean or Uniform Value	*z*-score range
Word shape	CVCCVC	N/A
Phonotactic Probability		
Segment	0.180	-0.199 to 1.24
Biphone	0.006	-1.43 to 1.20
Phonological Neighborhood Density	0.000	N/A
Phonological Neighborhood Frequency	0.000	N/A
Word-Likeness		
Initial stress	2.617	-1.93 to 1.20
Non-initial stress	2.750	-1.53 to 1.53
Phonetic Complexity	6.167	-1.133 to 1.78
Syllable Frequency (per million words)		
1st syllable	1.000	0.00 to 0.00
2nd syllable	0.083	-0.289 to -.298
Uniqueness Point	3	0.00 to 0.00
Orthographic Transparency	1:1	N/A
Syllable Boundary Clarity	10/12 clusters illegal in onset and offset	N/A

Note: Values for each factor determined per data available and/or criteria provided in the following literature: Phonotactic Probability: Vitevitch & Luce (2005); Neighborhood Density and Neighborhood Frequency: Vitevitch & Luce (1998); Phonetic Complexity: Stoel-Gammon (2010); Word-Likeness: Gathercole (1995); Syllable Frequency: Baayen et al. (1995); Uniqueness Point: Mliner (2010); Syllable Boundary Clarity: Treiman & Zukowski (1990).

Table 4

Nonword stimuli and foils.

Initial Stress	Syllable Boundary	Foil 1	Foil 2	Foil 3
/'viʃ.fuz/	/viʃ.'fuz/	/ʃɛv/	/zom/	/laf/
/'zæl.ʃov/	/zæl.'ʃov/	/vif/	/miʃ/	/ləz/
/'ʃiv.lom/	/ʃiv.'lom/	/vuz/	/fəʃ/	/mɛl/
/'fæz.mul/	/fæz.'mul/	/vim/	/zof/	/ʃəl/
/'lam.vef/	/lam.'vef/	/fɛʃ/	/miv/	/zol/
/'muf.zoʃ/	/muf.'zoʃ/	/faz/	/vim/	/ʃəl/
/'foʃ.vul/	/foʃ.'vul/	/ʃaz/	/zɪf/	/miv/
/'lev.mof/	/lev.'mof/	/vəl/	/faʃ/	/zim/
/'mæz.fuv/	/mæz.'fuv/	/vɛf/	/ʃom/	/zel/
/'ʃɛm.liz/	/ʃɛm.'liz/	/fuʃ/	/zev/	/mæl/
/'vul.ziʃ/	/vul.'ziʃ/	/ʃaf/	/fɛv/	/lom/
/'zɪf.ʃom/	/zɪf.'ʃom/	/vul/	/feʃ/	/məz/

Table 5

Summary of participant demographics and screening measures – Experiment 1.

Measure	AWNS	AWS	*p*
Age (years)	20.36 (2.62)	22.27 (6.45)	.374
Handedness Score[ϕ]	66.20 (24.40)	67.76 (33.14)	.904
Onset Identification: *Real Words*[ƚ]	13.82 (2.56)	13.00 (3.61)	.546
Onset Identification: *Nonwords*[ƚ]	15.91 (3.39)	14.18 (4.09)	.294
Onset Generation: *Real Words*[ǂ]	19.73 (0.47)	18.82 (0.87)	.006*
Onset Generation: *Nonwords*[ǂ]	19.55 (0.69)	19.45 (1.21)	.831
Rime ID[a]	14.91 (0.30)	14.82 (0.60)	.660
Rime Generation[b]	14.55 (0.69)	14.36 (0.67)	.538
Forward Digit Span[#]	11.00 (1.90)	10.82 (2.27)	.841
Backward Digit Span[#]	8.18 (2.32)	6.55 (2.162)	.102
Nonword Repetition[ƚ]	12.80 (2.04)	12.36 (1.96)	.624
Baseline Reaction Time[∆] (msec)	318.65 (32.63)	323.14 (44.19)	.789

Note: mean scores; standard deviation in parenthesis; * $p < 0.05$

ϕ: Edinburgh Handedness Inventory (Oldfield, 1971: left = < -40, right = > +40, ambi = -40 to +40)

ƚ: Comprehensive Test of Phonological Processes subtest (Wagner et al., 1999: range 0-20)

ǂ: Comprehensive Test of Phonological Processes subtest – adapted (range 0-20)

a: criterion (Sasisekaran & Byrd, 2013: range 0 – 15)

b: criterion (Sasisekaran & Byrd, 2013: range 0 – 15)

#: Wechsler Adult Intelligence Scale – Fourth Edition (Wechsler, 2008: range 0-20)

∆: simple motor RT task (Sasisekaran et al., 2006)

Table 6

Unusable tokens, error tokens, and disfluent tokens within data corpus – Experiment 1.

	AWNS					AWS					**TOTAL**
	C1	C2	C3	C4	***N***	C1	C2	C3	C4	***n***	**N**
Initial corpus	132	132	132	132	**528**	132	132	132	132	**528**	**1056**
Lost Trials											
NR	*4*	*5*	*3*	*2*	***14***	*3*	*2*	*2*	*1*	***8***	***22***
OVR	*3*	*7*	*9*	*6*	***25***	*1*	*2*	*2*	*0*	***5***	***30***
O	*12*	*5*	*7*	*8*	***32***	*7*	*6*	*4*	*5*	***22***	***54***
TD	*1*	*1*	*1*	*1*	***4***	*0*	*0*	*0*	*0*	***0***	***4***
Usable n	112	114	112	115	**453**	121	122	124	126	**493**	**946**
Errors											
FN	*5*	*11*	*12*	*11*	***39***	*9*	*15*	*18*	*24*	***66***	***105***
PE	*2*	*3*	*4*	*2*	***11***	*8*	*6*	*8*	*9*	***31***	***42***
SE	*2*	*0*	*1*	*0*	***3***	*1*	*1*	*0*	*0*	***2***	***5***
SLD	*0*	*0*	*0*	*0*	***0***	*6*	*5*	*5*	*6*	***22***	***22***
Usable n	103	100	95	102	**400**	97	95	93	87	**372**	**772**

Note: Numbers in italics were removed from the data set. AWNS: adults who do not stutter; AWS: adults who stutter; IS: initial stress condition; SB: syllable boundary condition (non-initial stress); C1: first consonant position (<u>C</u>VCCVC): C2: second consonant position (CV<u>C</u>CVC); C3: third consonant position (CVC<u>C</u>VC); C4: fourth consonant position (CVCCV<u>C</u>); NR: no response; OVR: overlapping verbal response; O: outlier; TD: technical difficulties; FN: false negative response; PE: phonemic error; SE: stress error; SLD: response with stuttering-like disfluency.

Table 7

Mean monitoring latencies for consonant position of CVCCVC nonwords with initial stress as first metrical property in adults who do and do not stutter.

	AWNS			AWS		
	M	Lower *CI*	Upper *CI*	*M*	Lower *CI*	Upper *CI*
C1	891.23	810.14	972.32	988.00	906.91	1069.09
C2	1100.21	997.62	1202.81	1095.64	993.04	1198.23
C3	1143.22	1035.50	1250.93	1170.63	1062.92	1278.35
C4	1159.91	1038.69	1281.14	1201.85	1080.63	1323.08

Note. Reaction times measured in milliseconds. AWNS: adults who do not stutter; AWS: adults who stutter; C1: first consonant position (<u>C</u>VCCVC): C2: second consonant position (CV<u>C</u>CVC); C3: third consonant position (CVC<u>C</u>VC); C4: fourth consonant position (CVCCV<u>C</u>); CI: 95% confidence interval calculated using standard error of the mean.

Table 8

Participant characteristics for adults who do not stutter – Experiment 2.

			Conversational Sample			Reading Sample						
P	Gender	Age	%SLD	Severity Score	Stuttering Severity	%SLD	Severity Score	Stuttering Severity	Overall %SLD	Overall Severity	Previous Dx	Self-ID
23	M	19	0.33	1	N/A	0.00	1	N/A	0.17	1.00	N	N
24	F	21	1.00	1	N/A	0.30	1	N/A	0.65	1.00	N	N
25	M	21	1.67	1	N/A	0.59	1	N/A	1.13	1.00	N	N
26	M	25	1.00	1	N/A	0.00	1	N/A	0.50	1.00	N	N
27	M	25	1.67	1	N/A	0.00	1	N/A	0.84	1.00	N	N
28	F	26	1.00	1	N/A	0.00	1	N/A	0.50	1.00	N	N
29	M	25	2.67	1	N/A	1.48	1	N/A	2.08	1.00	N	N
30	M	20	0.33	1	N/A	0.30	1	N/A	0.32	1.00	N	N
31	M	22	1.67	1	N/A	0.59	1	N/A	1.13	1.00	N	N
32	F	36	1.04	1	N/A	0.60	1	N/A	0.82	1.00	N	N
33	F	18	0.67	1	N/A	0.00	1	N/A	0.34	1.00	N	N
M		23.45	1.19	1.00	N/A	0.35	1.00	N/A	0.77	1.00	Y=0	Y=0
SD		4.74	0.66	0.00	N/A	0.43	0.00	N/A	0.51	0.00	N=11	N=11
Min		18	0.00	1	N/A	0.00	1	N/A	0.15	1		
Max		36	2.67	1	N/A	1.48	1	N/A	2.08	1		

Note: P: participant; %SLD: percentage of stuttering-like disfluencies per sample; M: male; F: female; Age: age in years; Severity Score: score on scale of stuttering severity (O'Brian et al., 2004); Previous Dx: previous diagnosis of stuttering; Self-ID: participant self-identification as an adult who stutters; Y: yes, N: no; mod: moderate; mild-mod: mild to moderate; sev: severe; ex sev: extremely severe; N/A: not applicable.

Table 9

Participant characteristics for adults who stutter – Experiment 2.

			Conversational Sample			Reading Sample						
P	Gender	Age	%SLD	Severity Score	Stuttering Severity	%SLD	Severity Score	Stuttering Severity	Overall %SLD	Overall Severity	Previous Dx	Self-ID
34	M	22	7.67	5	mod	4.18	3	mild	5.93	4.00	Y	Y
35	M	21	2.33	2	very mild	4.12	2	very mild	3.23	2.00	Y	Y
36	F	22	4.00	4	mild-mod	0.90	2	very mild	2.45	3.00	N	Y
37	M	21	3.67	3	mild	2.95	3	mild	3.31	3.00	Y	Y
38	F	22	4.00	2	very mild	3.87	2	very mild	3.94	2.00	N	Y
39	F	19	2.33	1	N/A	3.88	2	very mild	3.11	1.50	Y	Y
40	F	20	1.00	1	N/A	2.67	2	very mild	1.84	1.50	N	Y
41	M	27	7.00	1	N/A	7.14	2	very mild	7.07	1.50	Y	Y
42	M	19	24.82	9	ex sev	40.83	9	ex sev	32.83	9.00	Y	Y
43	M	28	3.00	3	mild	0.89	2	very mild	1.95	2.50	Y	Y
44	M	24	8.33	5	mod	7.37	5	mod	7.85	5.00	Y	Y
M		22.27	6.20	3.27	mild	7.16	3.09	mild	6.68	3.18	Y=8	Y=11
SD		2.83	6.31	2.30	N/A	10.83	2.07	N/A	8.49	2.12	N=3	N=0
Min		19	1.00	1	N/A	0.89	2	N/A	1.84	1.5		
Max		28	24.82	9	ex sev	40.83	9	ex sev	32.83	9		

Note: P: participant; %SLD: percentage of stuttering-like disfluencies per sample; M: male; F: female; Age: age in years; Severity Score: score on scale of stuttering severity (O’Brian et al., 2004); Previous Dx: previous diagnosis of stuttering; Self-ID: participant self-identification as an adult who stutters; Y: yes, N: no; mod: moderate; mild-mod: mild to moderate; sev: severe; ex sev: extremely severe; N/A: not applicable.

Table 10

Summary of participant demographics and screening measures – Experiment 2.

Measure	AWNS	AWS	*p*
Age (years)	23.45 (4.97)	22.27 (2.97)	.506
Handedness Score[ϕ]	67.32 (43.41)	52.64 (62.85)	.531
Onset Identification: *Real Words*[ƚ]	11.91 (3.39)	12.36 (3.61)	.764
Onset Identification: *Nonwords*[ƚ]	12.82 (4.22)	12.00 (4.75)	.674
Onset Generation: *Real Words*[ǂ]	19.36 (0.92)	19.36 (0.81)	1.000
Onset Generation: *Nonwords*[ǂ]	19.36 (0.67)	19.55 (0.52)	.488
Rime ID[a]	14.91 (0.30)	14.91 (0.30)	1.000
Rime Generation[b]	14.27 (0.91)	14.64 (0.67)	.298
Forward Digit Span[#]	8.82 (1.25)	11.09 (2.26)	.010*
Backward Digit Span[#]	5.82 (1.72)	6.82 (1.47)	.159
Nonword Repetition[ƚ]	12.18 (1.47)	12.27 (1.74)	.896
Baseline Reaction Time[Δ] (msec)	319.30 (25.67)	336.43 (38.74)	.238

Note: mean scores; standard deviation in parenthesis; * $p < 0.05$

ϕ: Edinburgh Handedness Inventory (Oldfield, 1971: left = < -40, right = > +40, ambi = -40 to +40)

ƚ: Comprehensive Test of Phonological Processes subtest (Wagner et al., 1999: range 0-20)

ǂ: Comprehensive Test of Phonological Processes subtest – adapted (range 0-20)

a: criterion (Sasisekaran & Byrd, 2013: range 0 – 15)

b: criterion (Sasisekaran & Byrd, 2013: range 0 – 15)

#: Wechsler Adult Intelligence Scale – Fourth Edition (Wechsler, 2008: range 0-20)

Δ: simple motor RT task (Sasisekaran et al., 2006)

Table 11

Unusable tokens, error tokens, and disfluent tokens within data corpus – Experiment 2.

	AWNS					AWS					**TOTAL**
	C1	C2	C3	C4	***n***	C1	C2	C3	C4	***n***	**N**
Initial corpus	132	132	132	132	**528**	132	132	132	132	**528**	**1056**
Lost Trials											
NR	*1*	*2*	*0*	*1*	***4***	*3*	*3*	*5*	*5*	***16***	***20***
OVR	*2*	*1*	*0*	*3*	***6***	*3*	*2*	*0*	*4*	***9***	***15***
O	*3*	*5*	*7*	*3*	***18***	*7*	*2*	*2*	*4*	***15***	***33***
TD	*0*	*0*	*0*	*0*	***0***	*0*	*0*	*0*	*0*	***0***	***0***
Usable n	126	124	125	125	**500**	119	125	125	119	**488**	**988**
Errors											
FN	*11*	*17*	*14*	*17*	***59***	*10*	*26*	*20*	*22*	***78***	***137***
PE	*5*	*3*	*4*	*4*	***16***	*12*	*8*	*13*	*9*	***42***	***58***
SE	*1*	*1*	*1*	*2*	***5***	*9*	*9*	*7*	*3*	***28***	***33***
SLD	*0*	*0*	*0*	*0*	***0***	*2*	*3*	*2*	*1*	***8***	***8***
Usable n	109	103	106	102	**420**	87	87	87	89	**350**	**770**

Note: Numbers in italics were removed from the data set. AWNS: adults who do not stutter; AWS: adults who stutter; C1: first consonant position (<u>C</u>VCCVC): C2: second consonant position (CV<u>C</u>CVC); C3: third consonant position (CVC<u>C</u>VC); C4: fourth consonant position (CVCCV<u>C</u>); NR: no response; OVR: overlapping verbal response; O: outlier; TD: technical difficulties; FN: false negative response; PE: phonemic error; SE: stress error; SLD: response with stuttering-like disfluency.

Table 12

Mean monitoring latencies for consonant position of CVCCVC nonwords with syllable boundary as first metrical property in adults who do and do not stutter.

	AWNS			AWS		
	M	Lower *CI*	Upper *CI*	*M*	Lower *CI*	Upper *CI*
C1	931.33	841.42	1021.25	1066.88	976.97	1156.79
C2	1095.71	987.36	1204.06	1223.72	1115.37	1332.07
C3	1122.50	993.50	1251.50	1342.34	1213.34	1471.33
C4	1193.22	1062.43	1324.02	1320.61	1189.82	1451.41

Note. Reaction times measured in milliseconds. AWNS: adults who do not stutter; AWS: adults who stutter; C1: first consonant position (CVCCVC): C2: second consonant position (CVCCVC); C3: third consonant position (CVCCVC); C4: fourth consonant position (CVCCVC); CI: 95% confidence interval calculated using standard error of the mean.

Table 13

Mean latencies from previous and present analyses for adults who do not stutter when monitoring C1-C2 and C2-C3 latencies in $C_1VC_2C_3VC_4$ stimuli with initial and non-initial stress.

Study	Stress	C1-C2	C2-C3
Schiller (2005)	Non-Initial	25 ms	90 ms*
Wheeldon & Levelt (1995)	Mix	55 ms*	56 ms*
Wheeldon & Morgan (2002a, Experiment 1)	Mix	109 ms*	63 ms*
Wheeldon & Morgan (2002b, p. 516)	Mix	114 ms*	29 ms
Present data (Experiment 2)	Non-Initial	165 ms*	28 ms
Present data (Experiment 1)	Initial	210 ms*	43 ms
Sasisekaran et al. (2006)	Initial	214 ms*	35 ms

Note: * $p < .05$.

Table 14

Mean latency data from previous studies and the present study for adults who stutter when monitoring C1-C2 and C2-C3 latencies in $C_1VC_2C_3VC_4$ stimuli with initial and non-initial stress.

Study	Stress	C1-C2	C2-C3
Current data	Initial	108 ms	75 ms
Current data	Non-Initial	157 ms*	118 ms*
Sasisekaran et al. (2006)	Initial	306 ms*	6 ms

Note: * $p < .05$.

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