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Visual to auditory silent matching task in adults who do and do not stutter

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Visual to auditory silent matching task in adults who do and do not stutter

by

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Dedication

This thesis is dedicated to my family—my dad (popsicle), my mom, my brother, and my aunt Frances—for their continuing love, support, and encouragement throughout my life and graduate school. Thank you for believing in me and encouraging me to strive for the best. I also want to thank my friends, in and out of Austin, who provided me with comfort, joy, laughter, and support during graduate school. Graduate school friends, we did it! This experience would not have been the same without coffee shop "study" nights, words of encouragement, and "girl talk."

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Abstract

Visual to auditory silent matching task in adults who do and do not stutter

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The purpose of the present study was to investigate the role of phonological working memory in adults who do and do not stutter through a visual to auditory silent matching task. This task also explored the possible relationship between auditory processing and its ability to affect performance on the task. Participants were 13 adults who stutter (mean age = 28 years), matched in age, gender, handedness, and education level with 13 adults who do not stutter (mean age = 28 years). For the nonvocal visual to auditory task, participants silently read an initial target nonword and matched that target nonword to four subsequent auditory nonword choices. The participants completed this task for 4- syllable and 7- syllable nonwords (N = 8 per set). Results indicated that adults who stutter were significantly less accurate than adults who do not stutter at both syllable lengths. Our present findings support previous research that suggests less efficient phonological working memory in adults who stutter.

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Introduction

Stuttering is characterized by an atypical disruption in the forward flow of speech and is thought to be multi-factorial in nature (e.g., Bloodstein & Bernstein Ratner, 2008; Conture, 2001; Guitar, 2013; Smith, 1999; Yairi & Seery, 2011). Genetics, speech motor control, auditory processing and linguistic factors including but not limited to phonological considerations are among the factors that may contribute to the onset, development and persistence of stuttering. Specific to phonology, phonological working memory, or the ability to temporarily store and maintain information, appears to be impaired in adults who stutter (e.g., Byrd, Vallely, Anderson, & Sussmann, 2012; Byrd, McGill, & Usler, in press; Coalson & Byrd, in press). In vocal as well as nonvocal nonword repetition and phoneme elision tasks, adults who stutter (AWS) as compared to adults who do not stutter (AWNS) demonstrate reduced speed and accuracy (e.g., Byrd, McGill, & Usler, in press Brocklehurst & Corley, 2011; Postma, Kolk, & Povel, 1990; Sasisekeran, 2013). These findings suggest that even when adults who stutter do not have to vocally produce speech, differences still exist in comparison to their typically fluent peers. Additionally, the phonological encoding skills of adults who stutter appear to be uniquely compromised when there is an increase in cognitive demands (e.g., Bajaj, 2007; Byrd, Vallely, Anderson, & Sussman, 2012; Jones, Fox, & Jacewicz, 2012; Sasisekaran & Weisberg, 2014; Weber-Fox, Spencer, Spruill, & Smith, 2004).

Previous research has explored performance on auditory to auditory nonvocal tasks (e.g., Byrd, McGill, & Ulser, in press) but to the present author's knowledge, a study of visual to auditory matching performance has not been completed. In other words, past studies have employed nonvocal auditory to auditory tasks, which required the participant to hear a word and silently match that word to subsequent auditory choices. The present study employed a nonvocal visual to auditory task. The participants were instructed to silently read a visual stimulus and then silently match that visual stimulus to four auditorily presented answers.

A visual to auditory task differs from an auditory to visual task based on the initial input to the phonological loop system. The initial visual input requires the material to be transferred from an orthographic to phonological code and then it registers to the phonological store while initial auditory input is fed directly into the phonological store. Given that there are data to suggest that auditory processing may be another possible factor contributing to stuttering (Hall & Jerger, 1978; Rosenfield & Jerger, 1984), the exploration of whether first presenting the critical information via the visual system uniquely impacts performance on phonological tasks is warranted. The purpose of this present study is to increase our understanding of the potential contribution of phonological working memory to stuttered speech by comparing the performance of adults who do and do not stutter on a visual to auditory matching nonvocal task.

WORKING MEMORY

A fundamental aspect of cognition is working memory. Working memory, a limited-capacity system, provides the temporary storage and manipulation of information, allowing various cognitive activities to take place (Baddeley, 2007). Baddeley (2012) discusses a four-component model of working memory.

Central executive. The first component, the central executive, is thought to be the essential controller for overseeing and coordinating the other subsystems (visuospatial sketchpad, phonological loop, and the new component, episodic buffer). The central executive focuses and divides attention, switches between tasks, and interacts with working memory and long-term memory. Bajaj (2007) recognizes that understanding how the central executive functions and its relationship to stuttering may be necessary given that on a daily basis all speakers will need to modify their cognitive and motor performances based upon their internal and external environments. The present study is a single task experiment. Exploration of the central executive is limited to dual-task experiments; therefore, the role of the central executive will not be discussed with respect to the nature of the task and/or the results of the present study.

Visuospatial sketchpad. Another component of the working memory model that is not critical to the present study is the visuospatial sketchpad. Logie (2011) describes the visual spatial sketchpad in terms of a "visual cache", the visual short-term memory, which is a temporary storage for a single array, and an "inner scribe" which retains short sequences of movements. Without the inner scribe, the visual codes will decay in about two seconds. The inner scribe internally repeats the sequences, thus allowing the visual codes to be refreshed and held onto for longer periods of time. Because our task, reading nonword stimuli and matching them to four auditorily presented choices, does not involve visual matrix arrays or movement sequences, the visuospatial sketchpad rehearsal is not relevant to our study either, and, as such, will not be discussed further.

Phonological loop. A component of the working memory model that is critical to the present study is the phonological loop. According to Baddeley (2003), the phonological loop is comprised of two distinct systems, the phonological store and the subvocal rehearsal system. The phonological store temporarily houses phonological codes. These codes will decay in approximately two seconds unless refreshed by the subvocal rehearsal system. The subvocal rehearsal system or “inner speech” (Logie, 2011) is a silent verbal repetition process, where one mentally repeats a sequence to maintain the phonologically encoded contents of the store for longer periods of time (i.e., greater than two seconds).

It is important to note that in adults, visually presented material is transferred from a visual, orthographic representation to a sound-based or phonological code, which is then thought to activate the subvocal rehearsal system (Baddeley, 2003). On the other hand, for auditory information (speech), the input travels directly to the phonological store. See Figure 1 for a more detailed review of the phonological loop. Bosshardt’s (1990, 1993) results suggest less efficient subvocal rehearsal among adults who stutter than typically fluent peers. Subvocalizing more slowly may interfere with the ability to maintain information in the phonological store prior to production (Baddeley, 1986).

The nature of subvocal rehearsal among AWS warrants further exploration, especially with regard to its relationship to the activation of motor processes. Wilson (2001) indicates motor processes are activated during subvocal rehearsal. In contrast, Postma et al. (1990) contend minimal, if any, motor planning and execution is involved in silent reading tasks. Additionally, studies conducted with dysarthric and dyspraxic patients showed that subvocal rehearsal is not dependent on the integrity of overt articulation, but it is instead related to the ability to set up speech-motor programs which affects rehearsal (Baddeley & Wilson, 1985; Caplan & Waters, 1995). This suggests that difficulty setting up speech-motor programs may negatively affect subvocal rehearsal. Furthermore, studies in articulatory suppression which require participants to retain target words in working memory while overtly repeating words unrelated to the target (i.e., “the, the, the”) have had a negative impact on recall accuracy (Baddeley, Lewis, & Vallar, 1984). These results imply that subvocal rehearsal is critical for efficient phonological storage and retrieval.

Episodic buffer. Given limitations in the description and data to support its existence, it is not entirely clear whether the more recently added component of the working memory system, the episodic buffer, is relevant to our study. A short-term storage system with limited capacity, the episodic buffer integrates “multidimensional code” from different sources like the visuospatial sketchpad, the phonological loop, and long-term memory that bind together to create “chunks or episodes.” These “episodes” perceptually aid in short-term memory recall and may create new cognitive representations or aid in long-term learning (Baddeley, 2012).

Furthermore, Baddeley (2003) suggests that if the phonological store has a limited capacity and becomes filled, the excess information may spill over into the episodic buffer. It is possible that, in our study, because we don’t know the capacity of the phonological store, we may assume that information from the phonological loop overflowed into the episodic buffer. The episodic buffer supplements the limited capacity of the phonological loop by providing additional storage. It is necessary for this new concept, the buffer, to continue being explored in order to bring us closer to understanding its function.

Summary

There are significant data to support the idea that deficits in phonological encoding may contribute to stuttered speech (Anderson, 2007; Anderson & Byrd, 2008; Bosshardt, 1993; Byrd, Conture, & Ohde, 2007, Byrd, Vallely, Anderson, & Sussman, 2012; Byrd, McGill, & Usler, in press; Coalson & Byrd, in press; Hakim & Ratner, 2004, Ludlow, Siren, & Zikria, 1997; Sasisekaran & de Nil, 2006; Sasisekaran, de Nil, Smyth, & Johnson, 2006; Sasisekaran & Byrd, 2013; Weber-Fox et al., 2004, Nippold, 2002, 2012). If deficits or differences exist in any of the previous subsystems, differences in performance on phonological tasks may be observed. In addition to phonological working memory, auditory processing has also been suggested to compromise phonological performance of persons who stutter.

AUDITORY PROCESSING IN ADULTS WHO STUTTER

It has been suggested that auditory language processing deficits contribute to the difficulties persons who stutter have establishing and/or maintaining fluent speech (Biermann-Ruben et al., 2005; Weber-Fox & Hampton, 2008). In a study conducted by Weber-Fox and Hampton (2008), which eliminated overt speech demands, adults who stutter demonstrated atypical processing of auditory linguistic information despite scoring within normal range on formal language tests. Medwetsky (2006) suggests that an auditory deficit is often present without deficits in language abilities, cognitive processing, or pure-tone hearing abilities. Given the nature of the present task (visual to auditory matching), it is important to think about the relevance of auditory processing and the impact that an atypical auditory modality may have on distinguishing subtle phonological differences. Additionally, in the clinical realm, auditory feedback has been used to reduce stuttering, indicating that auditory processing and feedback play important roles in stuttering (Rosenfield & Jerger, 1984; Kalinowski et al., 1993). There may be a certain subset of adults who stutter who have a disruption in the encoding of auditory signals which in turn could lead to reduced efficiency in processing and monitoring auditory feedback. This deficiency in the processing of auditory information may contribute to stuttered speech. It is possible that an adult who stutters who has auditory processing difficulties may have difficulty monitoring and processing the subtle differences in phonemes. Thus, these adults may be able to encode, store, and retrieve the visual phonological information efficiently (the visual part of our task) but are inefficient in phoneme monitoring due to auditory discrimination differences (the auditory part of our task).

However, differences in the processing of phonological information have been observed when no auditory input or vocal output was required. Weber-Fox et al. (2004) compared the nonvocal rhyming abilities of adults who stutter to their typically fluent peers (n = 11 per group). Participants selected a “yes” or “no” button to indicate if the two visually presented words rhymed. Out of the four conditions, only one showed a talker group difference. This condition was considered to be the most phonologically challenging. In this specific condition, the participants were presented with two words that were orthographically similar but did not rhyme (e.g., “cost” and “most”). Weber-Fox et al. (2004) concluded adults who do and do not stutter are similar in their phonological encoding abilities until there is an increase in cognitive loads. The author suggests that as cognitive demands increase, the phonological encoding skills of adults who stutter may become vulnerable to decreased efficiency. As Hakim and Ratner (2004) noted “It is difficult to know whether weaknesses in responding to the tasks reflect difficulty in encoding the input, storing it in memory, or accessing it efficiently (p.194).”

PURPOSE AND HYPOTHESES

To review, the purpose of the present study is to explore the processing of orthographic and auditory phonological information in adults who do and do not stutter. We sought to eliminate the contribution of overt speech motor movements by employing a nonvocal visual to auditory matching task. If adults who stutter are deficient in their ability to encode the visual nonword stimuli or if their subvocal rehearsal is less efficient, then their ability to correctly match the preceding answer would be less accurate than their typically fluent peers. Specifically, we asked the following questions: a) Are adults who stutter as compared to adults who do not less accurate in their ability to match a visual target word to an auditory presentation of that word? b) Do 7-syllable nonwords place a higher cognitive demand on adults who stutter than 4-syllable nonwords, therefore decreasing their visual to auditory matching accuracy? We predict that adults who stutter will be less accurate, regardless of syllable class, relative to adults who do not stutter. If 7-syllable nonwords words place a higher cognitive demand on adults who stutter, then we predict that these adults will show decreased accuracy as compared to the 4-syllable nonword class.

Method

Participants

Approval for the completion of this study was provided by the author's university Institutional Review Board and informed consent was obtained for each participant. All participants were compensated for their participation. To qualify for inclusion, participants had to meet the following criteria: (a) native English speaker (n= 11 for the group of adults who stutter; n = 13 for the group of adults who do not stutter) or an English speaker with native competency; (n = 2 for the group of adults who stutter) (b) between the ages of 18 and 65 years old; (c) no prior history of speech and/or language disorders (with the exception of stuttering for the adults who stutter); and (d) no neurological, social, emotional, or psychiatric disturbances. One adult who does not stutter was excluded from participation because of failure to meet one or more of the aforementioned inclusion criteria. Twenty-six adults who do (n = 13; M = 28 years; range = 20 -42; n = 5 females; n = 8 males) and do not stutter (n = 13; M = 28 years; range = 19- 42 n = 5 females; n = 8 males) matched for age (+/- 3 years), gender, and education-level met the inclusionary criteria for participation in this study.

All 13 of the adults who stutter who participated in the study had reportedly received a formal diagnosis of stuttering and received prior speech therapy for stuttering. Every participant who stutters also self reported as a person who stutters.

Receptive and expressive vocabulary was assessed using the *Peabody Picture Vocabulary Test, Fourth Edition* (PPVT-IV; Dunn & Dunn, 2007) and the *Expressive*

Vocabulary Test- Revised (EVT; Williams, 2007). Additionally, the Phoneme Elision, Blending Words, Rapid Digit Naming, and Non-word Repetition subtests from the *Comprehensive Test of Phonological Processing* (CTOPP: Wagner, Torgesen & Rashotte, 1999) were administered. We administered these tests to ensure that: (1) there were no participants in either group who had receptive or expressive vocabulary skills that were below normal limits; (2) we had similar distribution of vocabulary performance between the two groups of participants; and (3) there were no speech and/or language differences that may mitigate the findings. Independent t-tests conducted on the mean scores demonstrated that the performances of adults who stutter (M= 107.77; SD = 11.76) and of adults who do not stutter (M=115.15; SD=11.35) did not significantly differ for receptive vocabulary; t(24)=1.63, p = 0.15. T-tests also revealed that the performances of adults who stutter (M= 108.69; SD = 9.07) and of adults who do not stutter (M=113.69; SD=9.21) did not significantly differ for expressive vocabulary; t(24)=1.39, p = 0.24. Likewise, no significant differences were found between the talker groups for CTOPP subtests Phoneme Elision (PE), Blending Words (BW), or Rapid Digit Naming (RDN). (CTOPP-PE: AWS M=9.08, SD = 2.02; AWNS M=10.54, SD=2.15; t(24)= 1.79,p=.14; CTOPP-BW: AWS M=9.85, SD = 2.51; AWNS M=10.54, SD=2.15; t(24)= .076,p=.46; CTOPP-RDN: AWS M=9.23, SD = 4.04; AWNS M=11.15, SD=2.11; t(24)=1.52,p=.14). Independent t-tests conducted on the mean scores demonstrated that performances of adults who stutter (AWS M=9.69, SD = 2.63) and of adults who do not stutter (AWNS M=12.38, SD=1.26) significantly differed on the CTOPP Nonword Repetition (NWR) subtest; t(24)= 3.33, p=.012.

Stuttering severity was determined from a recorded, 5-minute conversational sample. Stuttering severity ratings were assigned to each participant who stutters using the Stuttering Severity Instrument-3 (SSI-3; Riley, 1994). The samples were analyzed by undergraduate, graduate, and a PhD student(s). Two participants received a rating of "very mild," six participants received a rating of "mild," one participate received a rating of "moderate," two participants received a rating of "severe," and two participants received a rating of "very severe." A PhD student and an undergraduate research assistant trained in disfluency count analysis assessed inter-rater reliability of stuttering severity for speech samples. Eight of the 26 participants (30%; 4AWNS, 4 AWS) were randomly chosen to determine inter-rater reliability. For AWS, inter-rater reliability was within two points on the SSI-3 for the four participants. Thus, the inter-rater reliability was found to be Kappa =0.94. There was 100% agreement for the severity ratings for all four AWNS participants, with no stuttering-like disfluencies noted during the conversational sample. Participant descriptive characteristics are summarized in Table 1.

STIMULI DEVELOPMENT

The present study employed nonword stimuli. The use of nonword stimuli is a common way to test phonological working memory. Nonwords force the individual to rely on the phonological loop (Gathercole, Willis, Baddeley, & Emslie, 1994) because the individual does not encounter the effects of prior lexical knowledge (i.e., semantic, orthographic, or phonological representations) (Montgomery, 2004).

A total of 16 nonwords consisting of 4- and 7- syllables (n = 8 per syllable length category) were selected from the nonword stimulus list developed by Byrd and et al. (2012). Nonwords were controlled for segmental phonotactic probability, biphone phonotactic probability, and real wordlikeness.

Nonwords were also controlled for phonotactic complexity using the Vitevitch and Luce (2004) web-based method of calculating segmental and biphone phonotactic probabilities. The mean sum of segmental probability was 1.437 for the 4-syllable nonwords and 1.676 for the 7-syllable nonwords. The mean sum of the biphone probabilities was 1.024 for the 4-syllable nonwords and 1.029 for the 7-syllable nonwords. Segmental and biphone sums for both syllable length categories were low in phonotactic probability as Vitevitch and Luce (1998) defined high phonotactic probability for nonwords as <1.

As described in Byrd et al. (2012), the nonwords were controlled for real wordlikeness as well. Thirty adults rated the nonwords according to the wordlikeness scaled used by Gathercole (1995). Participants were instructed to rate the spoken nonword on a 5-point scale with 1 indicating “very unlike a real word” and 5 indicating “very like a real word”. They were also told that the rating should not be based on comparing the non-word to an existing real word, but on whether the nonword’s sound pattern could exist in the English language. Mean wordlikeness ratings of nonwords were 2.1666 for the 4-syllable nonwords and 2.416 for the 7-syllable nonwords. Thus, all words were comparable in their rating of wordlikeness, ranging from “very unlike a real word” to “unlike a real word.”

To create the foils for the visual to auditory matching stimuli, a phoneme was omitted, substituted, or added to the target nonword. With the exception of the sixth syllable, initial and final consonants were deleted, substituted, or added to/from all syllables at least once, as consistently as possible, and in random order across syllable lengths. Due to construction of the nonwords, the sixth syllable never contained a final consonant to be deleted. Therefore, the foil stimuli were variations of the target nonword. See Table 2 for a complete list of the stimuli used in the nonvocal visual to auditory matching task.

STIMULI RECORDING AND PRESENTATION

A female native speaker of Standard American English recorded the nonword stimuli on a Dell computer using Computerized Speech Lab equipment in a sound treated room. To control for prosodic variation across syllable lengths, each recorded production of the nonword stimuli and foils were stressed on the first syllable. The microphone was placed approximately six inches from the speaker.

The experimental stimuli were presented using Microsoft PowerPoint. The audio stimuli played through ROKIT powered 5 speakers, which sat on the same table as the computer. Each participant sat nineteen inches from the computer screen. The audio stimuli presentation order for each syllable length was randomized using Microsoft Excel. In each task, eight 4-syllable nonwords were attempted before the more challenging 7-syllable nonwords. Participant responses were recorded with a digital video camera and Olympus digital recorder.

DETERMINING MAXIMUM WORD READING TIME

To help us determine the number of seconds (length of time) participants need to accurately read and repeat a given nonword, a pilot nonword reading task was completed. Thirteen adults who do not stutter and two adults who do stutter (severity rating of severe) read four 4-syllable length nonwords and four 7-syllable nonwords. These eight words were not included in the experimental study. The participants were told to read the nonwords aloud as many times as needed until they felt they had achieved a correct pronunciation.

Overall, the longest silent word reading time for the adults who do and do not stutter was at the 4-syllable class was 12.86 seconds and for the 7-syllable class was 16.99. Therefore, during the experimental task, the maximum word reading time was set to thirteen seconds for the 4-syllable length nonwords and seventeen seconds for 7-syllable length nonwords. None of the participants exceeded this allotted time.

PILOT STUDY

One adult male who does not stutter (age 27 with master's degree) completed a pilot study of the experimental task. The pilot study allowed us to ensure that our directions were clear and that the participants would be able to navigate the experiment as intended. Based on the pilot, the directions were revised to include: "Read the word silently to yourself" and "Please wait until all four words have been presented through the speakers before you move the mouse to make your selection." The pilot also resulted in moving the speakers from the floor to the table where the computer sat.

EXPERIMENT

The visual to auditory matching task required participants to read the target nonword silently and then identify the target nonword from a set of four auditorily presented nonword options. One of the four nonwords played was identical to the initial target nonword, the other three nonwords were foils. After the four words were auditorily presented, the participants used their mouse to choose "Word 1" for the first word they heard, "Word 2" for the second word they heard, and so on. Before beginning the experimental task, each participant completed a practice set which included two 4-syllable nonwords and two 7-syllable nonwords.

Prior to beginning the experiment, participants were read the following instructions, "A single target nonword will appear on the screen. Read the target word silently to yourself. Then you will be presented with a screen that shows four boxes: "Word 1", "Word 2", "Word 3", and "Word 4". At the same time, you will hear an audio clip of four words. Use the mouse to select the box on the screen that matches exactly the target word you previously read. You will select "Word 1" for the first word you hear, "Word 2" for the second word you hear, and so on. Please wait until all four words have been presented through the speakers before you move the mouse to make your selection. Do you have any questions? When you are ready, click the mouse to begin."

DATA SCORING

The participant responses to the visual to auditory matching task were scored as either correct or incorrect. Both correct and incorrect responses of each participant were recorded online by hand during the experiment by the present author. A trained research assistant verified 30% of the participant's responses via review of the video file to ensure accuracy. The trained research assistant and the author's responses matched 100% of the time.

Results

To review, the purpose of the present study was to explore phonological working memory in adults who do and do not stutter through the use of a nonvocal nonword visual to auditory matching task.

Mean Number of Accurate Responses

Accuracy of response was analyzed using a Repeated Measures ANOVA with the between- subjects factor of Talker Group (AWS, AWNS) and a within-subjects factor of syllable length (4- and 7-syllable nonwords). The dependent variable was the mean number of accurate responses at each syllable length (see Figure 3). There was no main effect for syllable length $F(1,24) = 3.907$, $p = .060$, partial eta squared = .140. There also was no interaction between syllable length and talker group $F(1,24) = .080$, $p = .780$, partial eta squared = .003. There was a significant between-subjects effect for syllable length $F(1,24) = 15.077$, $p = .005$, partial eta squared = .283. Adults who stutter were significantly less accurate in their responses than adults who do not stutter regardless of syllable length.

Discussion

The purpose of our present study was to further investigate the relationship between phonological working memory and stuttered speech. A visual to auditory matching nonvocal task comprised of 4- and 7- syllable nonwords was used to identify if adults who stutter differed in their accuracy relative to adults who do not stutter. Results will be discussed regarding between and within group considerations.

ACCURACY REGARDLESS OF SYLLABLE LENGTH

It is important to note that the participants were instructed to silently read the target nonword and then silently choose the target nonword from a preceding set of four nonwords presented auditorily. We predicted that adults who stutter would be less accurate in their responses across both 4- and 7- syllable length nonwords than adults who do not stutter. As predicted, adults who stutter were significantly less accurate in their responses than adults who do not stutter. Other studies that employed nonvocal tasks have similar findings (Byrd, McGill, & Usler, in press; Brocklehurst & Corley, 2011; Postma, Kolk, & Povel, 1990; Sasisekaran, 2013). Together, these findings suggest that phonological working memory may be compromised in adults who stutter.

We assume that subvocal rehearsal was employed because the average length of the audio recordings for 4- syllable nonwords was 10.106 seconds and for 7- syllable nonwords was 11.680 seconds. It is thought that the subvocal rehearsal system begins about two seconds after initial encoding takes place. The auditory recording of words coupled with the reading of the initial visual stimuli is well over the standard two seconds, thereby requiring a need for the subvocal rehearsal system. On the other hand, it is difficult to differentiate whether the differences observed between groups can be attributed to a phonological encoding deficit or a less efficient subvocal rehearsal system. If participants incorrectly transfer the orthographic code to phonological code, then they will subvocally rehearse the wrong code, thus compromising their selection of the correct answer. This may lead a participant to select an inaccurate response.

Auditory processing and/or discrimination could also have affected accuracy of responses. Research suggests that auditory processing difficulties may be a contributing factor to stuttering (e.g., Biermann-Ruben et al., 2005; Hall & Jerger, 1978; Rosenfield & Jerger, 1984; Weber-Fox & Hampton, 2008). If a participant were unable to process the individual phonemes correctly, then matching the subsequent answer choices would be difficult. Our study cannot explain the potential impact of auditory difficulties. To do so, would have required a simultaneous pairing of an initial auditorily presented stimulus with a visual stimulus. Such a presentation would ensure that any disambiguous auditory information is supplemented and alleviated because of the visual representation of the nonword. Another possible approach would be to employ a nonvocal auditory to auditory task or a nonvocal auditory to written task. This type of task would help determine if there are auditory differences between adults who do and do not stutter.

The difference among groups may also be explained from a motor perspective. If in fact subvocal rehearsal activates motor processes in the absence of overt speech production (Aleman & van't Wout, 2004; Wilson, 2001), then it is expected that the adults who stutter would be less accurate than the adults who do not stutter. Adults who stutter have been shown to have less stable motor coordination and more variability in coordination of movement (Byrd et al. 2012; Namasivayam & Lieshout, 2008; Smith et al. 2010). The participants knew they would not have to speak; nevertheless, it is possible participants may have moved their lips or tongues to help with reading the visual nonword stimuli. Perhaps our instructions should have included “Please do not move your lips or tongue while silently reading”. There is always the possibility that if the lips and/or tongue were moving, a more significant motor component was introduced. Further research needs to be conducted to understand if motor processes are triggered by subvocal rehearsal.

Influence of Syllable Length

We hypothesized that the visual to auditory matching of 7- syllable nonwords would place a higher cognitive demand on adults who stutter than 4- syllable nonwords, resulting in lower accuracy of responses. Contrary to our prediction, there was no difference in accuracy between 4- and 7- syllable nonwords for the adults who stutter. The task may have been more challenging than initially predicted, contributing to the lack of difference in accuracy between syllable length. Our results suggest that phonological encoding was as efficient for lower cognitive demanding nonwords (4- syllable) as for higher cognitive demanding words (7-syllable), presuming 7- syllable nonwords are in fact more cognitively demanding. We assumed that 7- syllable words should be more demanding based on previous research which showed that longer words are more difficult to recall and repeat accurately because a person does not have as much time to subvocally rehearse and therefore maintain and/or refresh integrity of the representation prior to production (Baddeley, Chincotta, Stafford, & Turk, 2002). The efficiency of retrieval of information is thought to be sensitive to the rate at which items can be rehearsed (Baddeley, Thomson, & Buchanan, 1975; Schweikert & Boruff, 1986; Standing, Bond, Smith, & Isley, 1980). If we consider 7- syllable nonwords to be more cognitively challenging, then our current findings would contradict the past research which suggests that phonological encoding may be challenged as cognitive loads increase (e.g., Bajaj, 2007; Bosshardt, 1990,1993; Jones, Fox & Jacewicz, 2012, Sasisekaran & Weisberg, 2014; Weber-Fox et. al., 2004). However, an alternate interpretation of our findings is that the task was more difficult at the 4- syllable level than originally presumed.

FUTURE RESEARCH

Another potentially useful measurement would be to record time spent on the initial visual stimulus slide to see if differences exist between adults who do and do not stutter. Should adults who stutter take more time on the initial visual stimulus slide, we would interpret this as showing that they were less efficient at processing orthographic codes or orthographic patterns and transferring them to phonological code or that their phonological encoding is less efficient, therefore requiring more time to see and decode the nonword. It is important to consider how orthographic knowledge influences phonological processing of nonwords. Future studies could include a measurement of reaction time. A slower response time for adults who stutter may indicate vulnerability in phonological encoding. In our present study, we piloted the use of Microsoft PowerPoint to measure reaction time; however, after examining the data for 26 participants, we didn't think Microsoft PowerPoint yielded reliable results. There may be potential flaws due to the concurrent running of other programs on the computer in addition to Microsoft PowerPoint. To support more reliable results, the purchase of more expensive equipment that specializes in recording time (i.e., Presentation® or E-Prime®) may be necessary.

Conclusion

The present findings suggest that adults who stutter may have phonological working memory deficits as evidenced by a decrease in accuracy of responses in the nonvocal task. Our study may also indicate that there are no significant differences in the cognitive demands between 4- and 7- syllable nonwords unlike our assumptions, or that 4- syllable nonwords are more challenging than anticipated. It is unclear from our study whether differences between adults who do and do not stutter stem from inefficiencies in phonological encoding or subvocal rehearsal. However, our results support the notion that phonological working memory is compromised in adults who stutter, but future research is needed to understand the impact of auditory versus visual encoding and the exact subsystem involved in the process. We are presently completing an additional study, which uses a similar task, except the initial input of the target nonword stimuli (visual or auditory) differs. We are investigating if one input modality may be more compromising to phonological working memory or if they are equally challenging.

Table 1: Participant characteristics for adults who do stutter and adults who do not stutter.

Participant	Age	Handedness	Gender	Education Level	Severity	PPVT-4	EVT-2	CTOPP-PE	CTOPP- BW	CTOPP- RDN	CTOPP-NWR
1	22	Right	Male	College	ML	123	114	9	13	10	13
2	42	Right	Female	Graduate School	SV	105	105	4	10	9	8
3	19	Right	Male	College	ML	117	118	11	12	11	13
4	28	Left	Female	College	SV	106	113	11	6	10	9
5	42	Right	Male	Masters	MOD	107	106	10	9	9	11
6	27	Right	Male	College	VS	86	90	9	4	6	4
7	35	Right	Female	College	ML	107	110	7	11	2	10
8	31	Left	Female	College	ML	114	104	11	10	11	9
9	27	Right	Male	College	ML	96	102	11	10	20	7
10	20	Right	Male	College	VML	113	121	9	10	9	8
11	21	Right	Male	College	VML	127	115	8	10	7	11
12	20	Right	Female	College	ML	91	97	10	13	7	13
13	32	Right	Male	College	VS	109	118	8	10	9	10
14	21	Right	Male	College	N/A	108	102	10	11	12	13
15	25	Left	Female	College	N/A	117	120	12	14	8	12
16	23	Right	Male	College	N/A	128	116	4	11	12	12
17	32	Right	Female	College	N/A	136	120	12	14	9	14
18	27	Right	Male	College	N/A	109	112	11	12	12	14
19	19	Right	Female	College	N/A	98	104	12	12	12	14
20	35	Right	Male	College	N/A	107	104	11	14	9	10
21	27	Right	Male	College	N/A	113	116	11	13	12	13
22	19	Right	Male	College	N/A	126	116	11	10	9	12
23	34	Left	Female	College	N/A	113	104	11	13	16	13
24	39	Right	Male	Masters	N/A	110	115	11	10	12	11
25	25	Right	Male	College	N/A	129	136	12	13	12	11
26	42	Right	Female	Graduate School	N/A	103	113	9	13	10	12

Note: Peabody Picture Vocabulary Test-Fourth Edition (PPVT-4): Standard score (M=100, SD =15). Expressive Vocabulary Test-Second Edition (EVT-2): Standard score (M=100, SD=15). Comprehensive Test of Phonological Processing (CTOPP) subtests: Standard score (M=10, SD = 2). CTOPP subtests: PE = Phoneme Elision, BW = Blending Words, RDN = Rapid Digit Naming, NWR = Nonword Repetition. Severity: VM= very mild, ML = mild, MOD = moderate, SV= severe, VS= very severe.

Table 2: Nonvocal nonword task stimuli.

Four syllable nonwords	Seven syllable nonwords
1. JIG.VEN.TO.XILE	1. VAM.PON.TIG.EEZ.I.TRI.CAY
2. CAS.TI.PAIL.TY	2. DAY.BISH.OCK.SIN.ALL.O.BIT
3. AN.TIS.KOL.DATE	3. FO.MMI.GA.VE.LON.TI.PAN
4. DIG.AN.TUL.IN	4. GIS.TOR.AK.I.DO.PU.LIN
5. VAY.TAW.CHI.DOYP	5. IN.FAS.KO.VI.JI.DE.EN
6. DA.VON.OY.CHIG	6. JED.A.BUL.OS.KER.A.MIC
7. NY.CHOY.TOW.VUB	7. KA.DDEN.I.SO.NO.MA.CY
8. TAV.A.CHEE.NYG	8. SA.CON.IM.BEN.A.LO.PY

Figure 1. Schematic of proposed structure for phonological loop from Baddeley (2003).

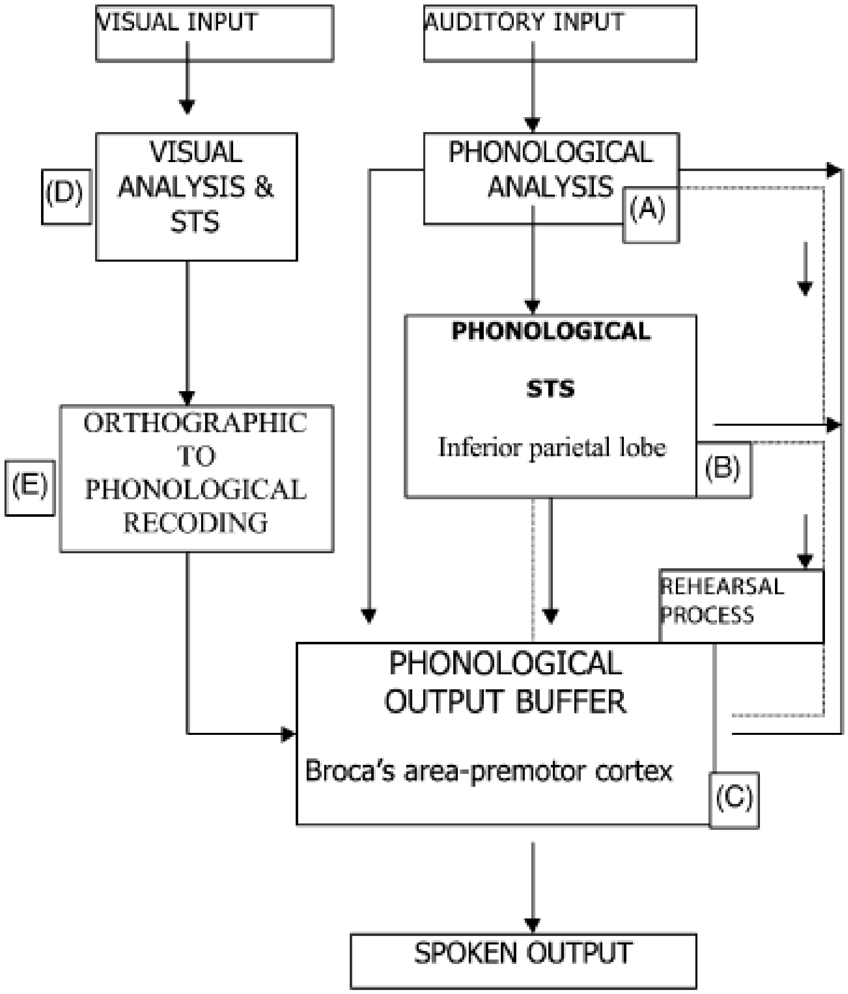
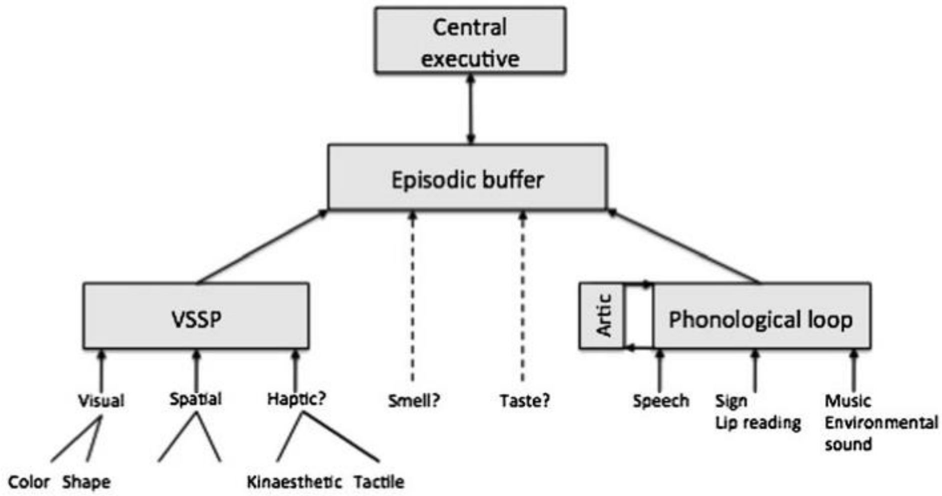
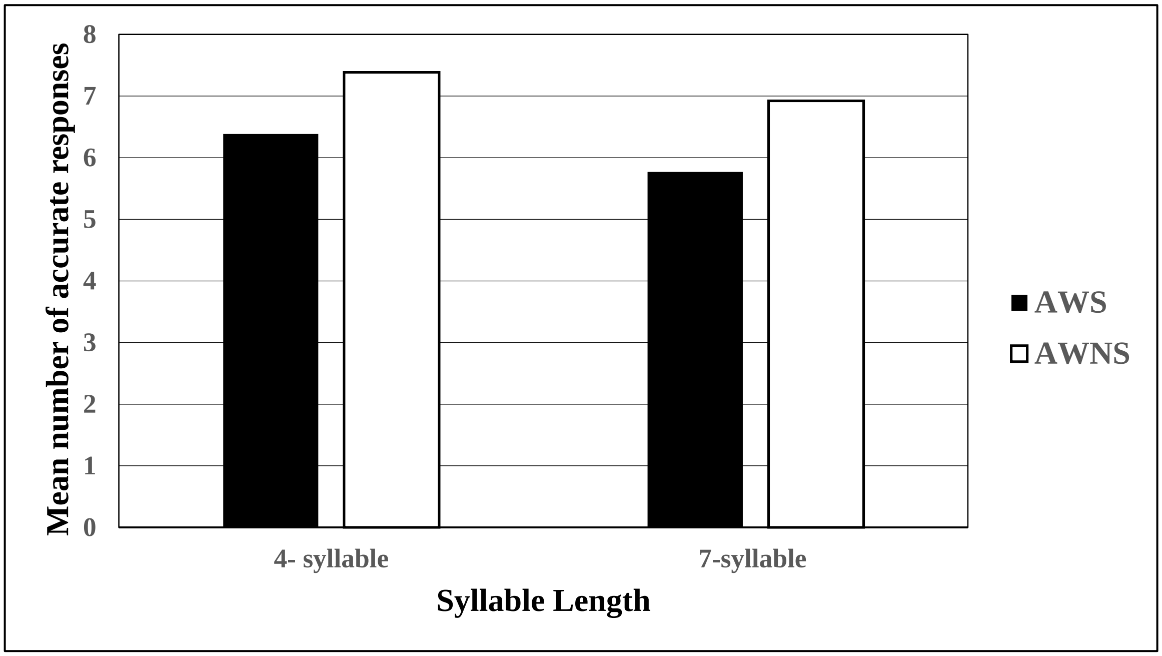


Figure 2. Schematic view of the flow of information from perception to working memory from Baddeley (2012).



(VSSP = visuospatial sketchpad).

Figure 3. The mean number of accurate responses of the nonword stimuli at each syllable length for adults who do (AWS) and adults who do not stutter (AWNS).



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